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CONTENTS

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[*Continued on page (III) of Cover.*

ELECTRONIC MUSICAL INSTRUMENTS AND THE DEVELOPMENT OF THE PIPELESS ORGAN

By G. T. WINCH,* Member, and A. M. MIDGLEY,† Associate Member.

(*Paper first received* 16*th June*, 1939, *in revised form* 10*th October*, 1939, *and in final form* 10*th May*, 1940; *read before the* TEES-SIDE SUB-CENTRE 6*th March*, 1940. *The paper would also have been read and discussed before* THE INSTITUTION *on the* 21*st December*, 1939, *but the meeting was cancelled owing to the war*.)

SUMMARY

Brief reference is first made to the history and development of musical instruments and the scales with which they are associated.

The principles of the design and operation of the pipe organ are referred to in so far as they have a bearing on the problems of the electronic organ, and the possibilities of electronic methods of producing music are indicated. All forms of electronic musical instruments are referred to, and classified according to the systems employed.

The main treatment of the paper concerns the design of electronic instruments which simulate the pipe organ, both in their playing technique and musical effect. The many engineering problems which arise in the construction of instruments of this type are dealt with in some detail. Finally, design and assembly details are given of a complete electronic organ, and reference is made to possible future developments.

CONTENTS

* The Research Laboratories of the General Electric Co., Ltd., Wembley, England. † Midgley Harmer, Ltd., and Midgley Electrical Instruments, Ltd.

CONTENTS—*continued*.

(1) INTRODUCTION

Although the main treatment of this paper deals with the electrical engineering problems which have arisen in the design and development of pipeless organs operating on electronic principles, the success of such instruments is so dependent on a thorough appreciation of the musical aspect of the problem that this paper would be incomplete if reference to the musical traditions and requirements were omitted.

Also, for the sake of completeness, brief descriptions of the development of many types of electronic musical instruments other than those simulating pipe organs have been included.

It is hoped that the short digression into the arts, which the authors have felt to be desirable in introducing the subject, will not entirely lack interest for the engineer, even if he feels, perhaps, that he has little in common with this side of the problem.

In the next Section, therefore, an attempt will be made to trace the history of musical scales and the development of the more traditional forms of musical instruments in so far as this has a bearing on the more recent developments of electronic types of musical instruments.

(2) MUSICAL SCALES AND INSTRUMENTS OF TRADITIONAL FORM

(A) Nature of Musical Scales and Harmonies

As far back as the early Chinese, Egyptian, and Greek civilizations, records show that simple forms of musical instruments existed, of the percussion, pipe, and stringed types. In fact, only this year two Egyptian trumpets, about 3 000 years old, were discovered in such a good state of preservation that they were able to be played, and the performance was broadcast by the B.B.C. The musical intervals which could be played on these early forms of wind and stringed instruments were limited to those corresponding to the simpler frequency ratios, and it is interesting to trace the parallel developments of musical scales from the early 5-tone scale used, for example, by the Chinese. Pythagoras is said to have been the first to have established the Greek diatonic scale of 8 complete degrees, i.e. 7 tones and the octave. Records reveal many different subdivisions of the octave; for example, one of the medieval Arabic scales shows a subdivision of 8 tones and the octave. All early music consisted of single-note melodic progressions, and variety was introduced by the use of the various modes of these diatonic scales. It is very interesting to note how many of the characteristic melodic progressions resulting from the use of these old scales persist to this day in Eastern music.

Harmony was a European discovery of only a few centuries ago, and even to-day it has not spread into Eastern countries to any great extent, at least in the form which we understand.

Strictly speaking the musical scale must be flexible if only to make possible the playing or singing of all the concords exactly in tune. It so happens that the positions into which the scale falls in order to produce theoretically correct major triads on the tonic, dominant, and subdominant, correspond to a *tuning* (as shown in Table 1) built up from the harmonics of the tonic, or key note (middle C = 256 c./s.); the frequencies of the resulting notes are also included. It will be seen from col. 2 that the harmonics form the notes of the diatonic scale at pitches one or more octaves higher than that containing the fundamental, or key note. For example, the 10th harmonic of middle C has a frequency of 2 560 c./s., producing a note E three octaves higher than that containing the fundamental.

Stringed instruments of the violin family can be played in the natural scale because the performer controls the effective length of the string with his fingers so as to produce intervals perfectly in tune. Because of the small departures from the natural scale of the pitch of the open strings, indicated in col. 8 of Table 1 for the scale of C, the performer must in certain cases avoid playing the open string if he wishes to play accurately in tune.

The ability of singers and instrumentalists who have developed a very critical ear and accurate technique, to produce music in just intonation is claimed to account for the very perfect harmonies peculiar to part-singing and chamber music.

In the 16th century, and for another 200 years in this country, keyboard instruments were tuned in mean-tone temperament, but some of the intervals were incorrect when the instrument was played in the more remote keys. It was this difficulty which led designers of early keyboard instruments to attempt a compromise in the form of divided "black" keys. Although this reduced the discordant effect, the playing technique was in consequence much more difficult. Actually, 53 subdivisions of the octave would be necessary in order to obtain satisfactory true intonation in all keys. This would necessitate an entirely different form of keyboard; and such a keyboard was devised by Bosanquet.[1]

But the inconvenience of such devices made them impracticable; and for that reason they could not compete with equal temperament, a *tuning* first proposed by Aron in 1529 and Zarliss in 1558. In this tuning the frequencies of successive semi-tones progressed in the ratio of $1 : \sqrt[12]{2}$. This resulted in all intervals being slightly imperfect in all keys, but by amounts which were not objectionable even to the musical ear, and a description of this system was published by Werkmeister in 1691. In 1722 John Sebastian Bach published the first book of his classic work, the 48 Preludes and Fugues for the "Wohltemperierte Klavier," covering all the major and minor keys and thus establishing this system which subsequently was universally adopted in European countries, and marked an important step in the development and design of keyboard instruments.

The absolute pitch of musical instruments has varied considerably in the past, but fortunately there has been a steady tendency towards standardization, and as the result of international co-operation the frequency of 440 c./s. for A has now been adopted in a number of European countries.[2]

(B) Harmonic Analysis and Mechanical Synthesis of Musical Sounds

Although early forms of music consisted of melodic progressions of single notes, even before the advent of harmony, the added artistic effect of producing such melodies on different instruments, each with its characteristic timbre or musical colour, was appreciated. With the introduction of harmony the musician was able to produce a much greater range of artistic effects by the judicious use of instruments of different timbre. These instrumental characteristics arose from the different structural forms of the musical instruments which in turn gave rise to the generation of series of harmonics, each at its own particular intensity level, so colouring the tone of the musical note produced. Helmholtz was the first physicist to investigate these effects, and his classic work,[3] together with that of later investigators, has shown how musical sounds can be analysed into their component frequencies of sinusoidal form, employing Fourier's mathematical methods of analysis. Also, that when components in the form of separately generated notes, produced by sinusoidal air displacement, are sounded simultaneously at the requisite strengths, the characteristic steady note timbre is synthesized in the ear. All these early investigations were carried out with the aid of mechanical resonators such as had been available to craftsmen throughout the centuries and which have been utilized in the development of the various forms of traditional musical instruments.

Table 1

Corresponding note	Scale of "just" intervals			Frequency of equal-temp. scale	Percentage difference, equal temp., from col. 2	Frequency of perfect fifths of stringed instruments	Percentage difference, perfect fifths, from col. 2
	Frequency	Frequency ratio to the tonic	Harmonic number				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
C^1	256	1	1	256	0	256	0
C#				271·222			
D	288	9/8		287·350	− 0·23		
D#				304·437			
E	320	5/4		322·539	+ 0·80		
F	341·333	4/3		341·719	+ 0·11		
F#				362·038			
G	384	3/2		383·566	− 0·11	384	0
G#				406·373			
A	426·667	5/3		430·538	+ 0·91		
A#				456·141			
B	480	15/8		483·263	+ 0·68		
C^2	512	2	2	512	0		
C#				542·445			
D	576			574·700		576	0
D#				608·874			
E				645·079			
F				683·437			
F#				724·077			
G	768/2 = 384	3	3	767·132	− 0·11		
G#				812·749			
A	853·4			861·077		864	+ 1·24
A#				912·282			
B				966·527			
C^3	1 024/3 = 341·333	4	4	1 024	0		
C#				1 084·890			
D				1 149·401			
D#				1 217·748			
E	1 280/3 = 426·667	5	5	1 290·159	+ 0·79	1 296	+ 1·25
F				1 366·875			
F#				1 448·154			
G	1 536/4 = 384	6	6	1 534·264	− 0·11		
G#				1 625·498			
A				1 722·155			
A#	(1 792)*	7	7	1 824·564	+ 1·82		
B				1 933·054			
C^4	2 048	8	8	2 048	0		
C#				2 169·780			
D	2 304/8 = 288	9	9	2 298·802	− 0·23		
D#				2 435·497			
E	2 560/8 = 320	10	10	2 580·318	+ 0·80		
F				2 733·750			
F#	(2 816)	11	11	2 896·309	+ 2·86		
G	3 072/8 = 384	12	12	3 068·540	− 0·11		
G#	(3 328)	13	13	3 250·997	− 2·32		
A				3 444·311			
A#	(3 584)	14	14	3 649·121	+ 1·82		
B	3 840/8 = 480	15	15	3 866·109	+ 0·68		
C^5	4 096	16	16	4 096	0		
C#	(4 352)	17	17	4 339·560	− 0·29		
D	4 608/16 = 288	18	18	4 597·604	− 0·23		
D#	(4 864)	19	19	4 870·995	+ 0·14		
E				5 160·637			
F				5 467·501			
F#				5 792·619			
G				6 137·083			
G#				6 501·994			
A				6 888·623			
A#				7 298·242			
B				7 732·218			

* The values in brackets are the harmonics of C^1, but differ in frequency from justly intoned notes of the chromatic scale shown. These intervals of the chromatic scale are derived from the cycle of diatonic scales built up from each note (col. 2—1st octave) as key note, by the simple frequency relationships in col. 3.

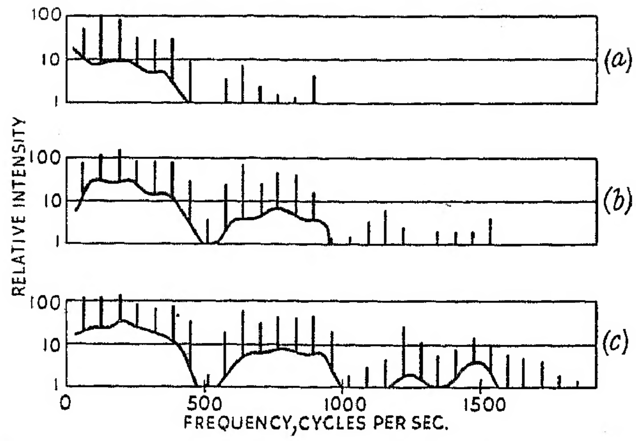


Fig. 1A.—Spectra of grand piano tones at 3 loudness levels (CC = 64 c./s.) (from Meyer and Buchmann[4]).

(a) Soft, *p*. (b) Mezzoforte, *mf*. (c) Loud, *ff*.

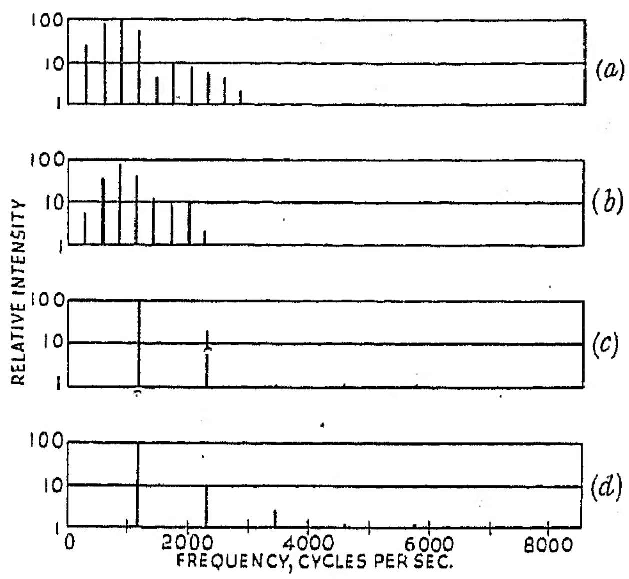


Fig. 1C.—Spectra of flute tones (from Meyer and Buchmann[4]).

(a) Metal flute (d^1 = 290 c./s.). (c) Metal flute (d^3 = 1 160 c./s.).
(b) Wooden flute (d^1 = 285 c./s.). (d) Wooden flute (d^3 = 1 140 c./s.).

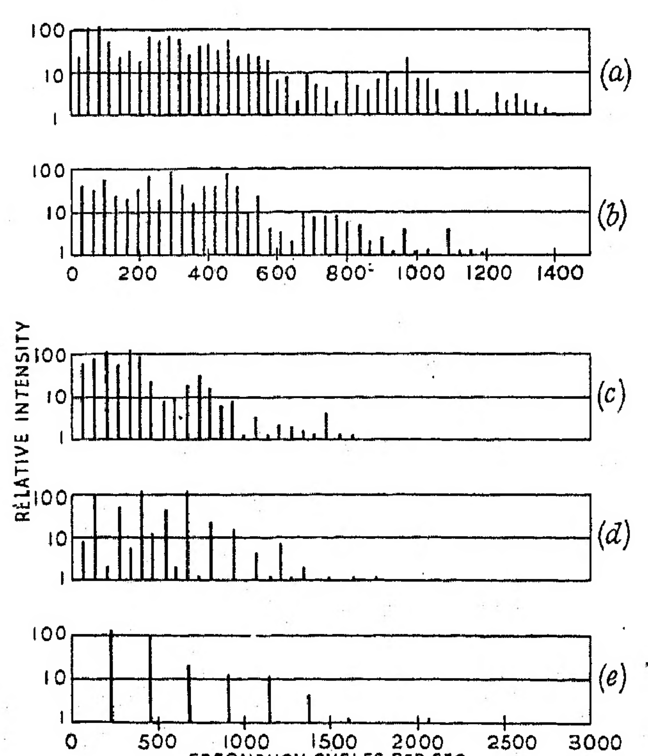


Fig. 1E.—Spectra of bassoon tones (from Meyer and Buchmann[4]).

(a) CCC = 32 c./s. (c) CC = 64 c./s. (e) b^1 = 230 c./s.
(b) AAA = 53 c./s. (d) C = 128 c./s.

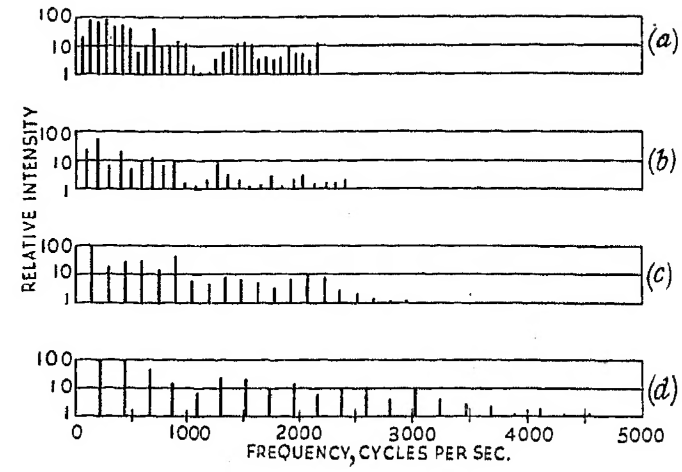


Fig. 1B.—Spectra of cello tones (from Meyer and Buchmann[4])

(a) Open C string (64 c./s.). (c) Open D string (144 c./s.).
(b) Open G string (96 c./s.). (d) Open A string (216 c./s.).

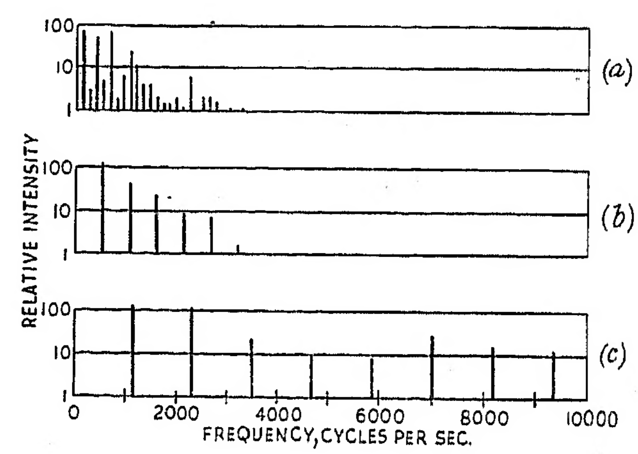


Fig. 1D.—Spectra of clarinet tones (from Meyer and Buchmann[4]).

(a) C = 128 c./s. (b) c^2 = 512 c./s. (c) d^3 = 1 160 c./s.

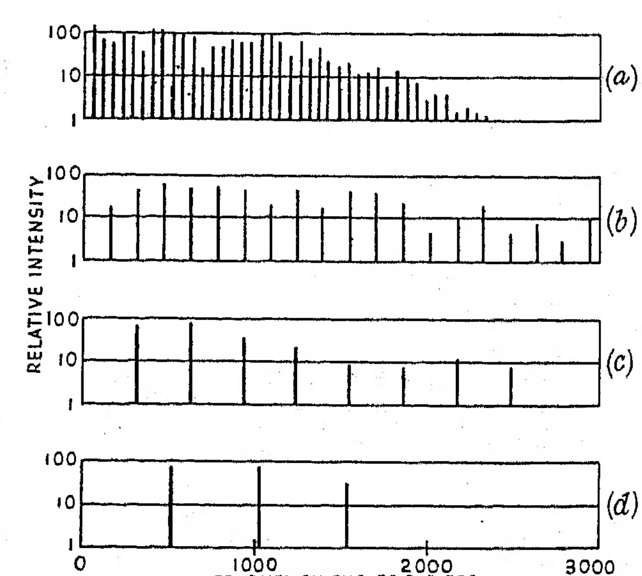


Fig. 1F.—Spectra of trombone tones (from Meyer and Buchmann[4]).

(a) BBB = 57 c./s. (c) $e\sharp^1$ = 306 c./s.
(b) E♯ = 153 c./s. (d) c^2 = 512 c./s.

Fig. 1 shows the spectra of some typical steady-tone air compression wave-forms produced by instruments of the orchestra, including a piano played at different

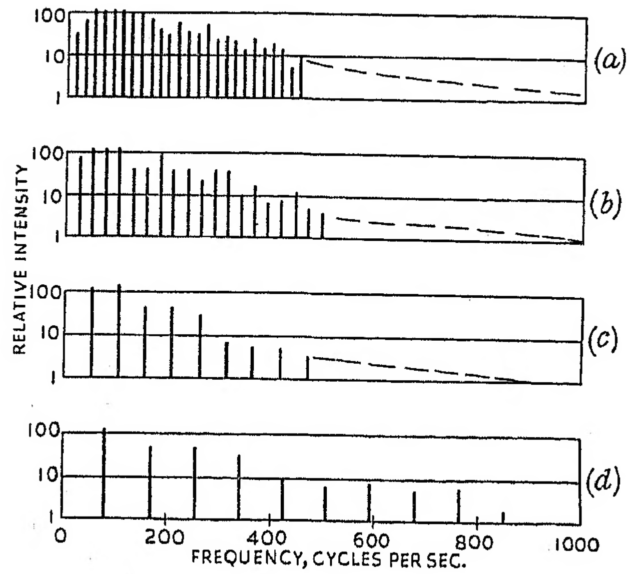


Fig. 1G.—Spectra of trumpet tones (from Meyer and Buchmann[4]).

(a) F♯ = 177 c./s. (c) c^2 = 512 c./s.
(b) c^1 = 256 c./s. (d) a^2 = 852 c./s.

loudness levels.[4] Fig. 2 indicates the sound spectra of the steady tones obtained from a number of organ pipes.[5] It may be concluded from these and other similar data that most musical instruments when played softly produce tones less rich in harmonics than those obtained when the instruments are played loudly. Generally speaking, as the loudness increases the number and intensity of the harmonics increases progressively.

But the tone of different musical instruments is recognized by the characteristic transient conditions at the beginning and end of the note as well as by the steady-state harmonic content. This is particularly the case with percussion instruments, and Trendelenberg and Franz[6] have shown that it is very difficult and often impossible to recognize the characteristic tone of organ pipes and some orchestral instruments if the steady tone only is heard without the characteristic starting and stopping transients. Recent investigations by Jones,[7] using recording methods of harmonic analysis, indicate in a striking manner the different time delays in the starting of the harmonic components produced when an organ pipe of the "lieblich gedackt" type is sounded. The non-harmonic "forerunner" of about 5·5 times the fundamental frequency which occurs during the starting period, in this case contributes to the characteristic quality of the tone, particularly in rapidly played passages.

In parallel with the development of electronic musical instruments, rapid development of electronic methods of harmonic analysis and synthesis[4, 5, 6, 7], have made possible investigations leading to a more complete understanding of tone production. Inventions relating to electronic musical instruments have been very numerous in recent years, and in the following survey it will only be possible to make reference to a few of the more important of these.

(C) Principles, Operation and Control of Pipe Organs

One of the most promising applications of electronic principles has been in the field of instruments which produce steady tones, such as the pipe organ. The advantage of electronic methods in this case is the potentially greater flexibility of control, compactness, and economy, as compared with that of the traditional pipe organ.

Unfortunately, it is only too apparent from a study of the patent literature on electronic organs that comparatively few inventors in this field have an adequate appreciation of the design, operation, playing technique, and musical scope of the modern pipe organ.

For this reason, and in order to avoid any misconception of the magnitude of the problem with which designers of electronic instruments of this form are confronted, a brief description of the principles of operation and control of the pipe organ is given in this Section.

The pipe organ has very aptly been described as the "King of Instruments," as in effect it may be likened to a whole orchestra controlled by one performer, and it has a greater frequency and loudness range than any other single instrument. Although the principle of the pipe organ is familiar to physicists and engineers, the multiplicity of intricate control mechanisms necessary to ensure the present-day high standard of flexibility of control by the performer are probably only fully appreciated by the organ builder and those closely associated with this highly developed craft.

An organ may be likened to an orchestra of wind instruments, some of which simulate in their tone quality

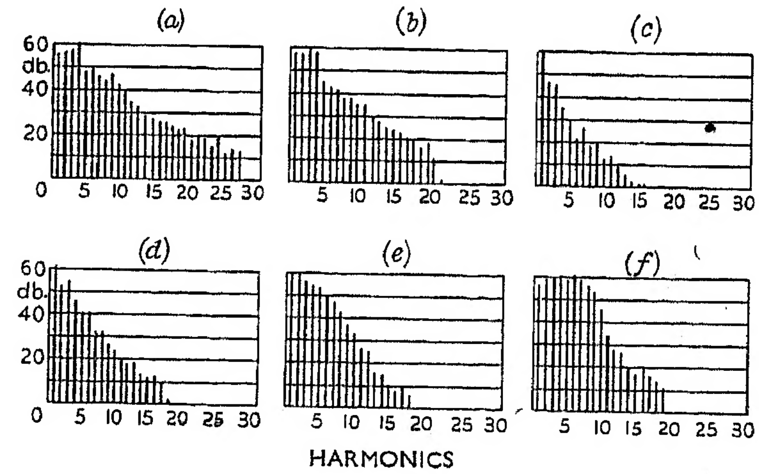


Fig. 2.—Spectra of organ pipes (C′ = 261·6 c./s.) (from Boner[5]).

(a) Viole d'orchestre. (d) Geigen diapason.
(b) Salicional. (e) Cornopean.
(c) Open diapason. (f) Trumpet.

that of stringed instruments, etc. Theoretically, one pipe per note is needed for each different tone colour, although in practice this is not always the case. For the sake of economy and convenience, by judicious arrangement of pipes and controls it is possible to reduce the number of pipes used. This is termed the "extension" or "unit" principle, details of which will be given later in this Section.

In the orchestra, not only does each different instrument produce a characteristic tone colour or timbre, but

each is associated with a particular loudness range, controllable by the player. In the organ, however, each rank of pipes (one pipe per note) has its characteristic timbre and loudness. The only way in which the loudness from ranks of pipes can be controlled is by operating them in a box made of sound-insulating material and provided with adjustable louvres in one side, so arranged that the extent to which they are open or closed is controllable by the performer.

Fig. 3 shows diagrammatically how in early organs each row of pipes of one characteristic tone colour and loudness was mounted on a sound board forming the top

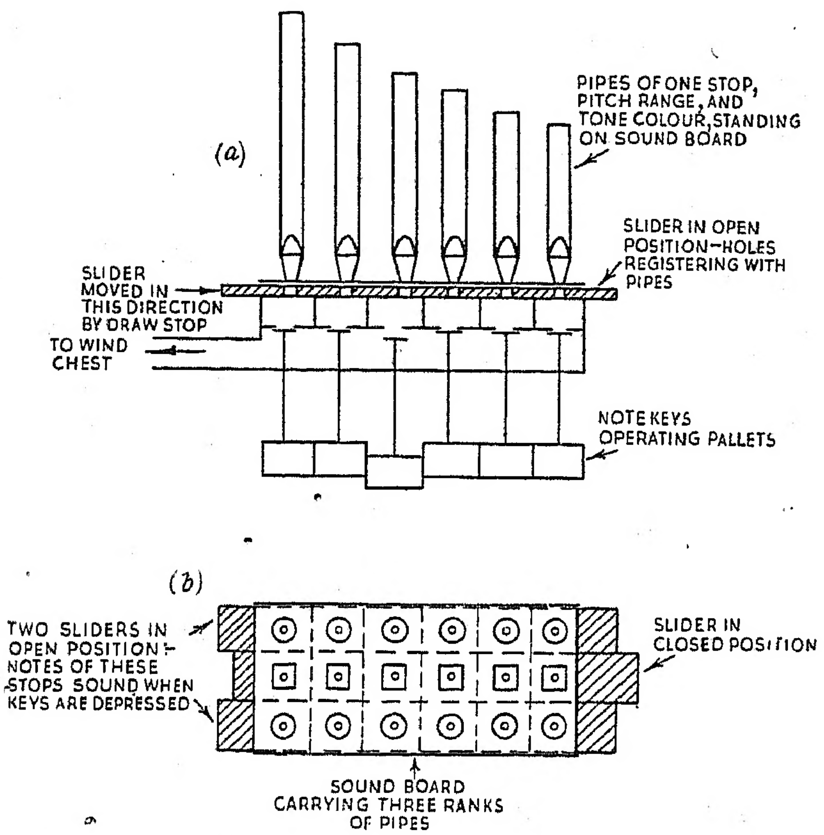


Fig. 3.—Arrangement of pipes, pallets, and draw stop sliders in simple form of organ.

(*a*) Elevation. (*b*) Plan.

of a wind chest. Under each row, or rank of pipes of one tone colour, sliders are arranged which are drilled with a series of holes. When the slider is critically located, these holes coincide with the holes in the sound board on which the pipes are standing, so that when this slide is moved lengthwise all the holes are closed. Below, and at right angles to the ranks of pipes, are arranged pallets which, when opened, allow wind to enter the compartment below all the pipes of the various tone colours which have the same fundamental frequency. If all the sliders are in the closed position, even if a pallet is opened, no note will sound because the wind is *stopped*. This is the origin of the term "stop" applied to the draw knob, stop key, or other means of controlling the position of the sliders. Clearly, if one or more sliders are moved into the "open" position by means of the controlling stops, the respective ranks of pipes will sound as the notes on the keyboard, which open the respective pallets, are depressed. So the performer may play melodies or harmonies on any chosen rank or ranks of pipes and obtain the corresponding timbre and volume associated with the respective pipes. In modern organs the note keys and draw stops operate the pallets and sliders or their equivalents in the appropriate manner by electrical or electro-pneumatic means. This results in much greater flexibility and ease of control.

Because of the limited number of harmonics of flute and diapason pipes, which form the groundwork of organ tone, in order to produce brilliant tone, particularly when many ranks of these pipes are sounding simultaneously, stops are provided which can be used to strengthen the harmonics of the notes being played. Such stops are termed "mutation stops," and are classified according to the pitch at which they sound. Actually, the conventional manner of indicating the pitch of organ stops is by reference to the length of the longest pipe in the rank, assuming it to be an open-flue pipe. In the case of other forms such as stopped pipes and reeds, the stop is still referred to in terms of the length of an open-flue pipe of equivalent pitch. Thus, a stop which sounds middle C at the same pitch as that of the note of this name on the piano will be called an 8-ft. stop, whilst one which sounds an octave lower when the same key is depressed is a 16-ft. stop. Table 2 indicates the pitch of these various nominal pipe lengths, their harmonic relation to one another, and the names by which they are designated on pipe-organ draw stops, or stop keys. In addition, the frequencies of the notes they produce are given, together with the nearest note of the equal-temperament scale (middle C = 256 c./s.). The whole range comprises stops of 32, 16, 8, $5\frac{1}{3}$, 4, $2\frac{2}{3}$, 2, $1\frac{3}{5}$, $1\frac{1}{3}$, $1\frac{1}{7}$ ft. In the case of ranks of pipes, such as the last four referred to, these are often grouped together under the title of "mixture." When a mixture stop is drawn, therefore, several ranks of pipes sound simultaneously. Such stops are not used by themselves but are only drawn when a large number of foundation stops are in action which in themselves are not rich in harmonics. This enhances the natural harmonics, and so gives brilliance to the tone. It will be noted that timbre and loudness are thus inevitably associated. In the organ, as in the orchestra, an increase in loudness brought about by the addition of louder stops, or instruments, results in an increase in the number and loudness of the harmonics.

But it is not sufficient to consider only this simpler form of organ, as such an instrument only allows the performer to play at any one time, melodies or harmonies of any chosen tone colour. By the addition of more keyboards, each one controlling in effect a separate organ, it is possible for the performer to play a solo with one hand at one particular loudness level and tone colour, at the same time accompanying this with the other hand on a second keyboard controlling a rank of pipes of contrasting timbre and loudness. In addition, heavy bass notes of chosen timbre may be played by the feet of the performer if a pedal board controlling yet another organ, is added. It is quite common for organs to be built having three keyboards, and large instruments have up to five, each of five octaves' compass. Actually, one giant instrument in America has seven keyboards, each keyboard of course being associated with what may be considered as a separate organ. These additional keyboards facilitate rapid changes of tone colour and

loudness, and enable the performer to be preparing new combinations of stops associated with the keyboards on which he is not actually playing at the moment.

In order to assist the performer in making rapid changes of stops on the several organs under his control, auxiliary mechanisms are provided, usually controlled by push-buttons under the respective keyboards, or manuals. Also, duplicate and additional controls in the form of toe pistons are mounted just above the pedal board, as shown in Fig. 26 (see Plate 5), which is actually a photograph of the console of an electronic organ in which the controls and layout are similar to that of a two-manual pipe organ. As was mentioned in the case of the simple form of pipe organ, in addition to the means of expression which the organist has at his command in the form of different tone colours and loudness resulting from various combinations of stops played from different manuals, the enclosing of one or more of the independent organs in a box with louvred shutters enables a "swell" effect to be obtained. In a pipe organ controlled from a console such as that in Fig. 26, the groups of pipes associated with the top and bottom keyboards are enclosed in boxes and the louvres are controlled, respectively, by the two balanced swell pedals shown in the centre and just above the pedal board. Depression of these swell pedals opens the louvres of the respective swell boxes to any required extent. These balanced swell pedals stay in any desired position when the foot is removed from the pedal, so giving the required crescendo effect to any particular stop or groups of stops in action.

Table 2

Nominal length of pipe	Harmonic series	Tone name	Diatonic interval	Note frequency: Scale of "just" intervals	Note frequency: Nearest note on equal-temperament scale
(1)	(2)	(3)	(4)	(5)	(6)
ft. 8	1	Prime	1	64	64 CC
			2	72	71·837 DD
			3	80	80·635 EE
$5\frac{1}{3}$		Quint	5	96	95·891 GG
			7	112	114·035 AA♯
4	2	Octave	8	128	128 C
			9	144	143·675 D
			10	160	161·269 E
$2\frac{2}{3}$	3	Twelfth	12	192	191·783 G
			14	224	228·070 A♯
2	4	Fifteenth	15	256	256 c^1
			16	288	287·350 d
$1\frac{3}{5}$	5	Tierce	17	320	322·539 e
$1\frac{1}{3}$	6	Larigot	19	384	383·566 g
$1\frac{1}{7}$	7	Septième	21	448	456·141 a♯
1	8		22	512	512 c^2
	9		23	576	574·700 d
$\frac{4}{5}$	10		24	640	645·079 e
$\frac{2}{3}$	12		26	768	767·132 g
	14		28	896	912·282 a♯
$\frac{1}{2}$	16		29	1 024	1 024 c^3
	18		30	1 152	1 149·401 d
	20		31	1 280	1 290·159 e
$\frac{1}{3}$	24		33	1 536	1 534·264 g
	28		35	1 792	1 824·564 a♯
$\frac{1}{4}$	32		36	2 048	2 048 c^4
	36		37	2 304	2 298·802 d
	40		38	2 560	2 580·318 e

It is interesting to note that, even with this method of loudness control, the resultant effect is to suppress the higher harmonics when the box is closed, so that, as with adding stops, a crescendo increases not only the loudness but also the proportionate strength and number of upper harmonics.

Although in the foregoing paragraphs brief mention has been made of the various methods of operation and control of a modern pipe organ, it will be obvious that a tremendous amount of detail is involved in the auxiliaries necessary to bring about this very flexible form of control, which cannot be dealt with here.[8] Actually, most of

the complicated controls of modern organs are operated by electrical or electro-pneumatic devices; in fact electrical methods of control have in recent years revolutionized the design of pipe organs.[9] One outstanding result of electric action and control has been the development of the "extension" or "unit" system, referred to earlier, which is widely used in the theatre organ and small pipe organ. This system enables very much greater flexibility to be obtained with a limited number of pipes, these being arranged in units of, say, 96 pipes of each tone colour, one pipe for each semitone of 8 octaves. From such a unit, by electrically controlled selecting systems resulting in overlapping as shown in Table 5, the approximate equivalent of stops of 16, 8, 4, and 2 ft., each of 5 octaves' compass, are obtained. Of course this method has its limitations and must be used with discretion.

Perhaps the authors may be forgiven for digressing to this extent from the main subject, as it will be apparent that the full significance of the advanced state of development of pipe organs must be appreciated when considering the application of electronic methods of producing instruments of the organ type if they are ever to be serious competitors of the present-day pipe organs.

(3) IDEAL REQUIREMENTS FOR MUSICAL EXPRESSION

(A) Scope and Limitations of Traditional Musical Instruments

Before considering electronic forms of musical instruments, it may be instructive to review the limitations of the older forms of instruments. As has already been mentioned, great skill and ingenuity have contributed to the present standard of perfection of the traditional forms of musical instruments, and, with these, musicians have produced musical masterpieces. However, it must not be overlooked that such instruments are dependent on the limitations of mechanical resonators, and this automatically determines their size, loudness, cost, degree of flexibility of control, and the tone colours which they can produce.

(B) Possibilities of Electronic Methods

The attraction of electronic methods of producing (as apart from reproducing) music is that, at least theoretically, it should be possible to generate electric current of any desired fundamental frequency and harmonic content. Such currents when amplified and converted to sound-pressure waves by means of loud-speakers should enable sound waves to be generated of any frequency and harmonic form, over an almost infinite loudness range. The flexibility of control of such methods of sound production should exceed that of any of the traditional forms of musical instrument, and there seems every reason to expect that the bulk and cost should be only a fraction of that of large and elaborate instruments such as pipe organs.

The following Sections will indicate to what extent these theoretical possibilities have been realized, and what may be expected of future developments.

(4) EVOLUTION OF MUSICAL INSTRUMENTS OF THE ELECTRONIC TYPE

So very many systems have been proposed for producing musical tones of different timbre by electronic methods, that it will only be possible to make brief reference to many of them. They will nevertheless be included for the sake of completeness and also in order to show what part they may have played in influencing later investigators. Also, reference will be made to some of the more important patent specifications as in many cases details of the systems have not been published elsewhere.

Table 3 indicates the various branches of electronic musical instrument development. It will be noted that these developments may be considered in three main groups, namely melodic or single-note instruments, harmonic or multi-note instruments of the percussion type essentially developed from the piano, and harmonic instruments simulating the pipe organ both in playing technique and musical effect. The developments will therefore be dealt with in this order, and only the last group of these will be considered in detail.

(A) Melodic or Single-Note Instruments

The Duddell singing arc[10] was probably the first melodic electronic musical instrument, although obviously its form and potentialities were not such as to attract interest in it as a serious musical instrument. In fact, only one serious attempt was made to construct an electronic form of musical instrument prior to the advent of the thermionic valve, namely that by Cahill[11] in 1897, and this will be dealt with when considering Group (C) (f) (ii) in Table 3.

In 1915 Lee de Forest[12] lodged the first patent application for a musical instrument utilizing thermionic valves for producing musical tones. His instrument consisted of a valve oscillator, the frequency of which was controlled by adjustable capacitance. The amplified audio frequency was then fed to a loud-speaker which produced the musical notes.

This was followed at a later date by a number of inventions in which various forms of oscillatory circuits were proposed, with the object of facilitating playing technique, and to some extent controlling the harmonic content or timbre of the notes produced by the superposition of formant frequencies. This method of timbre control attempts to simulate the effects which are observed in the case of vowel sounds in speech and in the notes produced by a few instruments of the orchestra such as the violin and bassoon. In these cases the tone is influenced by bands of resonant frequencies, or formants, common to a considerable pitch range. By separately generating these formant frequencies and superposing them on the note frequencies, the electronic instrument is made to produce a limited range of tone colours. In another variation of the circuit for producing these effects, neon lamps are incorporated in conjunction with condensers and discharging resistances to produce audio-frequency oscillations.[13] One example of the form of circuit used in this type of instrument is shown diagrammatically in Fig. 4.

Two instruments of this melodic type have attracted

Table 3

CLASSIFICATION OF ELECTRONIC MUSICAL INSTRUMENTS

Group (1)	Sub-group (2)	Division (3)
(A) Single-note form	(*a*) Electric arc	—
	(*b*) Oscillating valve circuits	—
	(*c*) Oscillating neon-lamp circuits	—
(B) Multi-note keyboard percussion form	(*a*) Struck string or tuned rod as generator	(i) Electromagnetic pick-up (ii) Electrostatic pick-up
(C) Multi-note keyboard organ form	(*a*) Maintained tuning fork or vibrator as generator	—
	(*b*) Maintained strings as generators	(i) Electromagnetic pick-up (ii) Electrostatic pick-up
	(*c*) Cathode-ray generator	—
	(*d*) Multiple oscillator circuits utilizing valves and neon lamps	(i) Thermionic-valve osc. circuits (ii) Neon-tube osc. circuits
	(*e*) Wind-maintained reeds as generators	(i) Electrostatic pick-up (ii) Electromagnetic pick-up
	(*f*) Rotary forms of generator	(i) Photo-electric (ii) Electromagnetic (iii) Electrostatic

Note:—There are two distinct methods which may be adopted with any of the above forms of instruments:—
(*a*) To generate directly complex wave forms of the required shape to produce the various tone colours.
(*b*) To generate series of sinusoidal wave forms of the required fundamental and harmonic frequencies, and by mixing circuits combine these to form the required complex wave forms and tone colours by synthesis.

considerable attention as solo instruments and may be quoted as examples. In the instrument invented by Theremin[14] and known as the Aetherophon, two supersonic valve oscillators produce beat frequencies in the audio range, the desired frequency or pitch of the note being controlled by the hand capacitance of the player. This is accomplished by moving the hand to different positions in space with respect to an electrode in the form of a vertical rod projecting from the oscillator cabinet. Starting and stopping of the notes is accomplished by means of a switch held in the other hand of the performer, but this latter development is due to Martin Taubman, and is incorporated in his instrument known as the Electronde. In the hands of an accomplished musician this instrument can be very effective for solo work of slow tempo.

The Trautonium, invented by Trautwein,[15] has a measure of timbre control which is realized by superposing formant frequencies on those generated by means of neon tubes. The pitch of the notes is in this case controlled by means of a variable resistance in the form of a spun-wire cord stretched over a steel band, the wire being pressed on to the band at the desired point by the performer. To ensure the correct positioning of the finger for any particular note, a dummy keyboard is arranged adjacent to the wire, thus indicating the contact positions for any given note within the compass of the instrument.

Instruments of this class do not lend themselves to development as multi-note instruments, for fairly obvious reasons, and consequently their scope has been strictly limited.

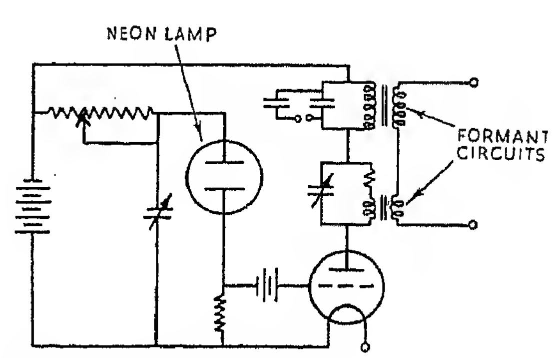


Fig. 4.—Neon-lamp oscillator circuit.

(B) Percussion Type, Keyboard-Controlled Multi-note Instruments of the Piano form

A type of instrument which has been developed mainly by Vierling and Miessner,[16] consists essentially of piano-type action and strings mounted on a frame in the conventional manner, but with no soundboard. The general form of arrangement adopted in such instruments is shown diagrammatically in Fig. 5, from which it is clear that if different excitation voltages are applied to the respective pick-up bars and the strings connected to the grid circuit of an amplifier, when the strings are

vibrated by the hammer blow the resulting variations in capacitance at the respective audio frequencies can be used to produce musical notes. The harmonic content of the notes will depend on the proportionate excitation of the various pick-up bars and their positions along the strings. The strings are usually struck by a hammer operated from the keyboard, as in a normal piano, although Palmgren[17] has suggested an electrostatic method of starting the vibration of the string. Various methods have been proposed for controlling the extent to which the starting transients are included in the component fed to the amplifiers for production by loud-speakers, and for controlling the harmonic content of the steady tone produced. Such instruments have a much greater dynamic range than normal pianos, this being made possible, of course, by the valve amplification and loud-speakers used. Also, greater variations in tone colour and wave-form envelope shape are at the command of the performer, although the playing technique is only a modification of that required for playing a normal piano.

Simple forms of such instruments have recently appeared on the market, in which, by means of electro-

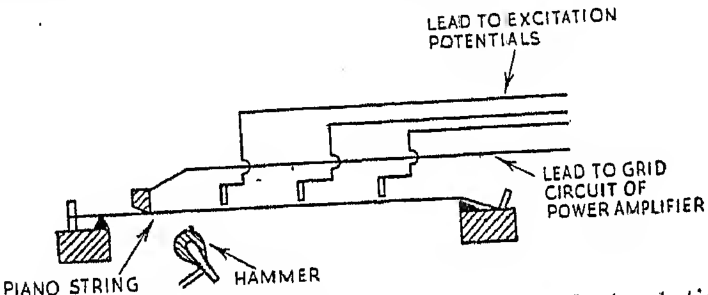


Fig. 5.—Struck string as generator, with electrostatic pick-up.

static pick-up and amplifier arrangements, quite a small instrument is made to produce tone more nearly approaching that of a grand piano. The volume can be set to suit the particular requirements, and in some examples, while playing, the performer has limited control over tone or volume in addition to that normally available to the pianist by keyboard technique.

(C) Electronic Instruments Simulating Pipe Organs

Reference to Table 3 shows that many different systems have been proposed, but unfortunately it is impossible in this brief survey to detail all the many ingenious variations. Only general descriptions of many of the systems will therefore be given.

Of the six sub-groups of group (C) in Table 3, only systems (C) (*d*) (i) using thermionic valves as generators, (C) (*e*) (i) using wind-maintained reeds with electrostatic pick-up arrangements, and (C) (*f*) (ii) and (iii) utilizing rotary generators of the electromagnetic and electrostatic forms, have reached the stage of development where full-compass organs are actually being built for the market. These systems will be dealt with under the respective headings in the next Section.

(5) THE PROBLEMS OF THE PIPELESS ORGAN

(A) The General Problem

From the foregoing Sections, and in particular Section (2) (C), it will be clear that the requirements are very exacting if an electronic instrument is to be built which will be competitive with modern pipe organs. It would appear that with electronic methods it should be possible to construct an instrument comparable with a pipe organ at a greatly reduced cost and of considerably smaller dimensions. This, it must be admitted, is one of the prime considerations behind the development of all commercially available instruments, and it is the attempt to simulate the tones of a pipe organ accurately, having in mind these commercial considerations, which calls for a high degree of skill and ingenuity on the part of the inventor and designer.

Considering the requirements for the imitation of the pipe organ, these may be divided into eight main problems, as follow:—

(a) Pitch Range.

The range of pitch of the fundamentals of all the notes of a pipe organ is from the lowest note of the 32-ft. pedal stops with a frequency of approximately 16 c./s., to at least the top note of the 2-ft. manual stops with a

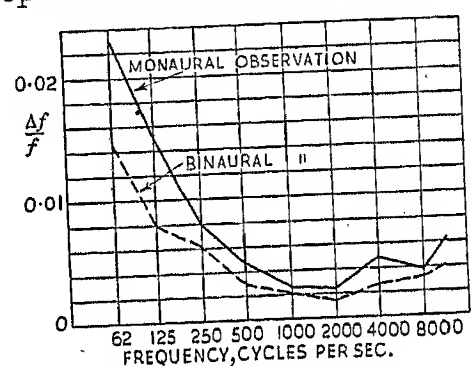


Fig. 6.—Relation between pitch discrimination and frequency of pure note at sensation level 40 db. above threshold (Shower and Biddulph[18]).

frequency of the order of 8 000 c./s. Actually, in larger instruments some of the mutation stops may extend to higher fundamental frequencies. Also, the harmonics of notes of some of the tone colours it is desired to produce may extend to the limit of the audio-frequency range.

(b) Accuracy of Pitch.

As far as accuracy of pitch is concerned, it is important that all the octaves be perfect because when sustained notes are sounded in octaves, beats are immediately apparent if there is the slightest error in tuning. With regard to the intervals within the octave, a small departure from the theoretical equal temperament intervals is allowable, such for example as the differences which actually occur between individual pianos and organs due to the small differences in the technique of the tuners.

From the point of view of the design of an electronic organ it is important to know in terms of frequency what errors are tolerable in the case of these intervals within the octave.

Observations of the least perceptible difference in pitch of notes played successively have shown that the ear is most sensitive between 1 000 and 2 000 c./s. Shower and Biddulph[18] investigated this effect by means of a heterodyne oscillator which could be adjusted to produce notes of pure sinusoidal form at any desired frequency throughout the audio range. These results are summarized in Fig. 6, from which it will be seen that

monaural hearing is less critical than binaural hearing, the latter being susceptible to changes of 0·1 % in frequency in the most sensitive range.

In connection with the design of an experimental photoelectric organ in 1933, independent experiments were made by one of the authors[34] in collaboration with Messrs. Rushworth and Dreaper, organ builders, to determine the tolerable departures from the equal-temperament scale. Of three alternative designs involving departures of varying degrees, that shown in Table 4, when set up on a rank of pipes, was considered to be quite satisfactory. It will be seen that this confirms the results of Shower and Biddulph, namely that an error of the order of 0·1 % is tolerable. Of course, if sustained notes were played on an instrument having

Table 4

Differences of Frequency from Equal-Temperament Scale in Experimental Photo-Electric Organ

Note	Percentage error in frequency
C	+ 0·040
C#	− 0·105
D	− 0·112
D#	− 0·024
E	+ 0·115
F	− 0·070
F#	+ 0·126
G	− 0·010
G#	− 0·140
A	0
A#	+ 0·080
B	+ 0·100
C	+ 0·040

these inaccuracies of tuning, in unison with another instrument tuned exactly to the equal-temperament scale, noticeable beats would result. For this reason it would appear desirable to design instruments which will show the smallest possible departures from equal-temperament tuning. However, it should not be overlooked in this connection that it is the small tolerable errors of tuning of individual ranks of pipes in the case of the organ, or of the many instruments of the orchestra, resulting in a random distribution of frequency errors for each note played by the many pipes or individual instruments, which produce the chorus effect. This is not to be undervalued from the aesthetic point of view.

In the case of electronic instruments, with the exception of those utilizing synchronously-driven rotary forms of generator, the tuning adjustments will require to be made somewhat after the manner adopted with traditional forms of musical instruments. Such instruments are in consequence liable to go out of tune, and the frequency with which retuning will be necessary will, of course, depend on the particular design of the instrument.

With regard to instruments in group (C) (*f*), Table 3, the tuning is dependent on the following characteristics of the rotary generators:—

(i) The constancy of speed of the synchronously driven generator, including hunting effects introduced by the gears or other forms of drive.
(ii) The accuracy of the gear ratios employed to drive the shafts carrying rotors or groups of rotors.
(iii) The number of wave-forms, scanning lines, or equivalent, on the rotor and/or stator, and the accuracy with which the dividing is carried out.

These points will be dealt with more fully later in the paper.

It will be clear that once an instrument of any of the forms employing synchronously-driven generators has been designed and built, the tuning is fixed by the mechanical constants of the components. If, therefore, it is designed and constructed correctly it will always remain perfectly in tune; conversely a poor design and bad workmanship will result in an instrument which can never be in perfect tune.

(c) Intensity Range.

The loudness level from all pipes of the same timbre in a correctly voiced organ is generally adjusted to be sensibly equal throughout the whole pitch range, at least so far as the ear of the voicer is able to judge. Actually, in some cases a progressive increase in loudness is intentionally produced towards the higher notes in order that when chords are played the treble notes shall be prominent.

No figures are available for the actual (as apart from the relative) intensities of the various pipe tones in an organ, and therefore the initial setting in the case of electronic instruments is best carried out by aural methods. The values chosen are dependent to some extent upon the differences in sound intensity level which it is desired to obtain.

The range of intensity available in pipe organs varies considerably, depending on the size of the instrument. However, this will be in the region of 40 decibels for small instruments, extending to something approaching double this value for the one or two giant instruments which have been built.

The actual intensity of the full organ is a factor which can only be considered in relation to the acoustical properties of the building in which it is to be housed. The building also has an appreciable effect upon the actual quality of the various stops, but as this subject is a very extensive one it is not possible to treat it in detail here, and reference should be made to the various available publications.[19]

(d) Timbre Range and Starting Transients, etc.

The combined intensity and timbre range of pipe organs is greater than that of any other single instrument, and although the most characteristic tone colour is that of the diapason stops, many other tone colours are available, which may be used in combination with the foundation diapason tones, or for solo purposes and to produce special effects. These comprise imitations of string tones and most orchestral wind instruments, together with tones peculiar to the pipe organ.[20] Also, in the

case of the theatre organ, bells and percussion effects, etc., are included.

In order to imitate these many tone colours by electronic means, a knowledge of their respective sound-pressure wave-forms or the harmonic composition of the tones produced is necessary.

Meyer and Buchmann[21] and Boner[22] have analysed the tone of many instruments of the orchestra, and also that from organ pipes of various types. These and other similar data may usefully be used in designing the wave-form records or synthesizing arrangements for producing, by electronic means, the steady tone colour of these various instruments.

The problem of the starting and stopping characteristics is, however, a much more difficult one, and although very considerable inventive genius has been shown in the many proposals which have been made for accomplishing this, usually a compromise has to be adopted. Even if the exact harmonic content and time delays of the starting and stopping transients are not imitated, in some cases a measure of the effect is produced when the envelope of the sound wave-form is suitably controlled.

In the design of an electronic organ provision should be made, if possible, for the easy control by the performer of the harmonic content of the steady tone of at least one stop in addition to the means of tone control provided by stops imitating existing instrumental tone colours. This should prove of value to the musician in enabling him to use new tone colours, and also in investigations in harmonic synthesis which the electronic organ makes possible. Some provision must also be made for the control of the envelope of the complex sound-pressure wave-forms produced, if it is not possible to imitate exactly the required starting and stopping transient conditions.

In pipe organs the tremulant has come to be considered essential for producing vibrato effects when required; the electronic organ must therefore also be provided with suitable means for simulating this low-frequency fluctuation in pitch and/or volume.

(e) Harmonics—Tempered versus Untempered, etc.

Table 5 shows the fundamental frequencies in cycles per second of all notes of the tempered scale for a compass of 9 octaves, the pitch of the notes being based upon A (= 440 c./s.). When considering the design of electronic instruments of the form in which the different tone colours are obtained by synthesis, the question naturally arises from a consideration of Tables 1, 2, and 5, as to the possibility of using the notes of the tempered scale nearest to the corresponding harmonics required, instead of generating further exact harmonic frequencies. It will be seen that it is unnecessary to produce additional frequencies for use as harmonics which are already present as octaves, also that in many cases the frequencies of the notes of the chromatic scale nearest to the required harmonics are so little different that it would appear possible to use them as such. The possibility of using "tempered harmonics" is very attractive from the commercial point of view, when considering the size, weight, and cost of the generators.

The exact tones which it is desired to imitate must of course be known when this question is being considered, and if necessary, a compromise adopted.

The diagrams in Fig. 2 indicate the numbers and proportions of harmonics produced by various instruments. From these data it would appear that for the successful imitation of the steady tones of all the instruments cited, up to 50 harmonics are required. As the audible limit is in the region of 10 000 to 20 000 c./s., it follows that in the case of notes having fundamentals of frequencies approaching the top of the audible range the higher harmonics, even if present, will not be heard. However, these latter harmonics, by reason of the production of beats at lower frequencies within the audible range, may in some cases influence the resultant tone colour.[23]

It will also have been noted from Figs. 1 and 2 that in many cases the harmonics shown by analysis are very weak. Experiments carried out by one of the authors have confirmed that the presence of these weak harmonics, although often inaudible when radiated alone at the strength indicated by the harmonic analysis, when sounded in combination with the fundamental and other harmonics, markedly influence the tone colour of the resulting note of complex wave form. This was readily demonstrated by generating a tone of complex wave form, using electronic methods, in which one of the higher harmonics had a value approximately 40 db. below the intensity of the fundamental. Sounded by itself this harmonic was inaudible, and yet by changing its intensity level from 40 to 38 db., or from 40 to 42 db., the change in the tone quality of the resultant note was immediately apparent. This effect is most pronounced when the harmonic is in the region where the ear is most sensitive.

This latter point has a very important bearing on the range of intensity adjustment which must be available in an electronic instrument, and also the allowable tolerance in the relative intensity settings of the various harmonics of complex tones.

(f) Sinusoidal Wave-form Generators.

In electronic instruments of the form in which the tones of complex wave forms are synthesized by the combination of predetermined proportions of the various harmonic components of sinusoidal form, an important consideration is the relation between radiation intensities of sound pressure waves of sinusoidal form and the relative loudness as appreciated by the average ear throughout the audible frequency range. The curves published by Fletcher[24] showing these relationships at different intensity levels are given in Fig. 7. These data enable the radiation intensity of each harmonic of a synthesized tone to be determined in relation to the relative loudness required in the composite tone. For example, it is interesting to note the experience of one of the authors in adjusting the level of a 96-note sinusoidal wave-form generator so that the loudness of the individual notes of the equal-temperament scale throughout the compass of the instrument should be uniform. This was first carried out with the co-operation of a skilled organ voicer, and the levels so set up appeared to be uniform in loudness when notes of sinusoidal form only were played. However, when various tone colours were synthesized the notes of the resulting tone colours were non-uniform in loudness to a degree which was quite intolerable. The reason

Table 5

EQUAL-TEMPERAMENT FREQUENCIES
(A = 440 c./s.)

← 1 ft. Pitch →
← 2 ft. Pitch →
← 4 ft. Pitch →
← 8 ft. Pitch →
← 16 ft. Pitch →

	CCC	CC	C	C1	C2	C3	C4	C5	C6
C	32·703	65·406	130·812	261·625	523·251	1 046·502	2 093·004	4 186·008	8 372·016
C#	34·647	69·295	138·591	277·182	554·365	1 108·730	2 217·460	4 434·920	8 869·840
D	36·708	73·416	146·832	293·664	587·329	1 174·659	2 349·318	4 698·636	9 397·272
D#	38·890	77·781	155·563	311·126	622·253	1 244·507	2 489·014	4 978·028	9 956·056
E	41·203	82·406	164·813	329·627	659·255	1 318·510	2 637·020	5 274·040	10 548·080
F	43·653	87·307	174·614	349·228	698·456	1 396·912	2 793·824	5 587·648	11 175·296
F#	46·249	92·498	184·997	369·994	739·988	1 479·976	2 959·952	5 919·904	11 839·808
G	48·999	97·998	195·997	391·995	783·991	1 567·982	3 135·964	6 270·928	12 541·856
G#	51·913	103·826	207·652	415·304	830·609	1 661·218	3 322·436	6 644·872	13 288·744
A	55·000	110·000	220·000	440·000	880·000	1 760·000	3 520·000	7 040·000	14 080·000
A#	58·270	116·540	233·081	466·163	932·327	1 864·654	3 729·308	7 558·616	15 117·232
B	61·735	123·470	246·941	493·883	987·766	1 975·532	3 951·064	7 902·128	15 804·256

for this was obvious after measurements of the generator outputs had been made by means of a valve voltmeter, which indicated that the intensity levels were such that the condition for uniform loudness was not accurately satisfied. These inaccuracies introduced as the result of one single observer's judgment, together with those resulting from the effect of standing waves at the time the observation was made, appear in exaggerated form when several frequencies are combined, and subsequent adjustment of the generator output in accordance with the curves in Fig. 7 resulted in uniformity in loudness not only of the notes of sinusoidal form but also in the case of notes in all the synthesized tone colours.

Another important point which must not be overlooked in generators of this type is that accuracy of imitation of the steady tone colours depends on the purity of the wave forms of the individual harmonic components.

(g) Complex Wave-form Generators.

In these systems, in one of many ways, the sound-pressure wave-form of the various steady tone colours is recorded. These records, or others derived from them, are used in various forms of generators to produce the notes of complex wave form. Alternatively the desired wave forms may be derived from harmonic analyses and then transferred to the particular form required in the generator. Bearing in mind the number and relative

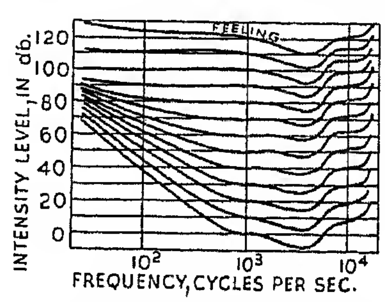


Fig. 7.—Contour lines of equal loudness for normal ear (Fletcher and Munsen[24]).
0 db. = 10^{-16} watt per cm^2 = 0·0002 dyne per cm^2

intensity of the various harmonics which are deemed necessary, it will be seen that very accurate recording is called for and many proposals have been made in connection with this very difficult technique.

From the reasoning given in the previous Section regarding the intensity levels of fundamentals and

harmonics, it follows that care must also be exercised in arranging the relative intensity levels of the various notes of different quality. In many such systems the construction proposed allows of some measure of compensation, either in a general way by suitably designing the characteristic of the amplifier, or in a more detailed manner by adjusting the intensity of each individual note in the various tone colours. However, this does not allow of the fine adjustment of the relative intensity of the individual harmonics to compensate for the acoustical properties of the particular building in which the instrument is housed, nor for the non-linear frequency characteristics of the amplifiers, loud-speakers, etc.

(h) Arrangement of Controls on Console.

The modern pipe organ console has been evolved as the result of years of development, and provides the means whereby the rapid changes of stops or groups of stops and the operation of expression controls can be brought about with a minimum of effort on the part of the performer. Whether in the development of the new electronic types of instrument it is wise to adhere strictly to the pipe organ console design is, of course, a somewhat controversial point. The argument in favour of the retention of the normal form of console is that the normal organ-playing technique, which can only be acquired after years of study, may still be used. It is clearly undesirable suddenly to introduce new methods of control which would seriously embarrass contemporary organists. However, there would appear to be no objection to providing alternative or additional means of expression.

(B) Frequency Generators—Electrical Considerations

The electrical problems involved in the various generator systems which have been proposed and used in the construction of full-compass organs will now be dealt with in the order in which they are classified in the sub-groups of group (C) in Table 3. As has been previously pointed out, sub-groups (C) (*a*), (*b*), and (*c*) have not been developed past the experimental stage and will therefore not be dealt with here.[25]

Of the three remaining systems, valve and neon-lamp generators are the ones in which no moving parts are required. In the case of reed generators, compressed air is needed to vibrate the reed, whereas the rotary-generator systems require synchronous electric motor drive.

(a) Multiple Oscillator Circuits.

The choice of oscillatory circuits for use in electronic musical instruments depends on many factors, the foremost of these being the stability of the frequency, as upon this depends the constancy of tuning of the instrument, the importance of which has already been stressed.

Many circuit arrangements have been suggested, each of which has its own peculiar limitations and advantages. For example, the use of one valve for each fundamental[26] and each harmonic naturally involves a large number of valves with their appropriate resonant circuits, cathode heater, and anode supplies, and the arguments in favour of the use of tempered harmonics would in this case materially assist in reducing the number of valves required. In order to reduce the number of cathode heater circuits, proposals have been made to use special valves in which one cathode functions for a number of independent oscillatory circuits.[27]

In 1930, Coupleux[28] demonstrated in France an organ having two manuals of three octaves' compass and pedals of normal compass, in which valve oscillatory circuits were used to generate complex wave-forms and filter circuits arranged to select the particular frequencies as required. Six months later he built a full-compass instrument, and in 1931 a two-manual and pedal organ having 22 stops and utilizing 250 valves was installed in a French church. Subsequently he built a three-manual and pedal organ of 76 stops incorporating 400 valves, which was installed in the studio of the Poste Parisien broadcasting station. In these instruments each note-frequency oscillator circuit was provided with means for adjusting the frequency so that the tuning could be carried out after the manner employed in tuning a piano or pipe organ, the constancy of pitch depending on the constancy of the valve characteristics and associated circuit components. The stop keys brought into action banks of filters for modifying the generated waveforms to produce the necessarily limited and somewhat arbitrary range of tone colours.

An experimental two-manual and pedal organ was built by Kock,[29] employing as generators neon lamps in oscillatory circuits; this was claimed to be very stable. Here again special filter circuits brought into action by the stop-key mechanism provided a limited range of tone colours.

Neither of these two forms of instrument has appeared in this country, nor apparently has been developed further, presumably due to difficulties in maintaining tuning sufficiently constant, limited tone colour range, and cost and bulk of the oscillatory and filter circuits.

Quite recently, an instrument of American origin,[30] developed by Williams and Hammond, made its appearance in this country. This can hardly be classed as an organ, although it can be used to produce sustained tones in addition to the many percussion and specialized effects. Like a piano, it has only one 6 to 7-octave keyboard and no pedals other than for controlling expression. In this instrument frequencies of the 12 notes of the top octave are generated by beat-frequency oscillators, many of the components of which are of special construction to ensure accuracy and constancy so that the generated frequencies shall be maintained to the necessary accuracy. The output from these 12 oscillators is connected respectively to frequency-halving circuits of special design which thus provide the note frequencies for the next lower octave of 12 semitones. This process is repeated for each octave down to the lowest note on the keyboard. The output from these divider circuits is then taken through control valves operated by the note keys to the amplifier, filter, and loud-speaker circuits. Three filter circuits controlling the top, middle, and bottom registers, give a measure of tone control, whilst special filter networks enable the envelope of the wave form of the note to be modified. Volume and tremolo effects are also provided. In all, about 160 valves are used in this instrument, which is able to produce a very large number of effects, including imitations of the harpsichord, guitar, and piano.

(b) Wind-Maintained Reeds as Generators.

This form of generator is seldom used for generating sinusoidal wave forms for synthesizing tone colours, as the complex nature of the vibrations of free reeds makes this extremely difficult.

The reed-type generator,[31] such as is incorporated in a two-manual and pedal instrument due to Hoschke, depends for its action upon the change in electrostatic capacitance between the metal tongue and small insulated electrodes placed above it. The reeds used for this purpose are similar to those employed in harmoniums, etc., and are vibrated by low-pressure wind.

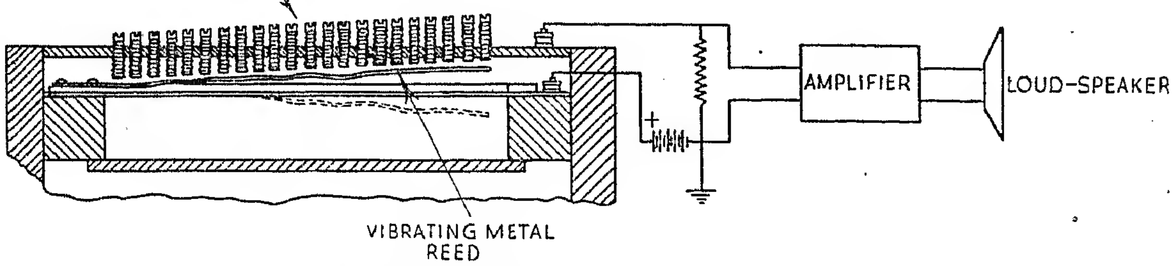


Fig. 8.—Wind-maintained reed generator.

By arranging a number of small screws immediately above the vibrating reed to act as pick-up electrodes, and connecting them in a circuit of the form shown in Fig. 8, a musical note of fundamental frequency of that of the reed will be obtained. The tone of this note will, of course, depend on the relative positions of the pick-up electrodes and the characteristics of the vibrating tongue.

There are, of course, other ways of controlling the tone produced by reed generators; some depend upon electrical considerations,[32] but most of these are based on practice common to reed-organ builders, such as shaping of the ends of the reeds in the manner shown in Fig. 9. If such reeds are used in conjunction with pick-up electrodes shaped as in Fig. 10, tones containing fewer harmonics will be generated. Reeds of the form shown in Fig. 11 make use of a variation in area to produce capacitance variations. The electrical output from this type of generator is very low, being in the region of -70 to -80 db. (zero level $= 0\cdot006$ watt) and consequently high-gain amplifiers, of the order of 100 db. gain, are required.

The stopping and starting characteristics of the resultant generated wave forms from this type of generator follow closely those of the actual reed. They may be modified to some extent by suitable resistance-capacitance networks connected between the reeds and the amplifying valves. In this way smoother tones may be produced.

(c) Rotary Forms of Generator.

(i) *Photo-electric Scanning.*

Mercadier, in 1890, made use of photoelectric scanning methods, but his proposals were in connection with the generation of a number of audio frequencies for use in multi-channel telegraphy.

Photo-electric methods of scanning used in electronic musical instruments may be divided into two main groups, namely those in which the light from an illuminated stationary slit is modulated by the passage in front of the slit of a variable-density or variable-area form of mask[33] after the manner of the sound track of a talking film, and those in which the illuminated mask of the wave form is stationary and is traversed by a series of slits one fundamental wavelength apart,[34] in the manner shown in Fig. 12. In both these forms the resultant modulated beam or beams of light are concentrated on to one or a small group of photo-electric cells, the output from which is fed to a power amplifier and loud-speakers.

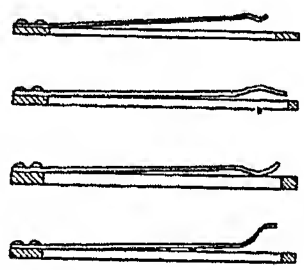


Fig. 9.—Examples of shaped reeds.

Many ingenious variations on these two forms have been proposed,[35] but only two complete full-compass organs have been constructed, one in France by Toulon and the other in Germany by Welte. Photo-electric organs of one and two manuals but no pedals have been constructed in America.[36]

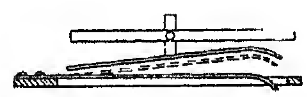


Fig. 10.—Example of shaped reed with special pick-up.

Toulon[37] was probably the first to construct a full-compass photo-electric organ, and his instrument utilizes stationary wave forms arranged radially, one row per tone colour, immediately in front of a rotating disc carrying slits in concentric rows at diameters corresponding to those at which the wave forms are placed, as shown in Fig. 12. The slits are spaced one fundamental

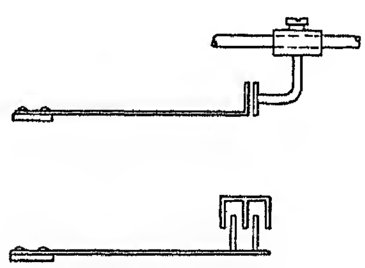


Fig. 11.—Variable-area reeds.

wavelength apart so that the wave masks are scanned at the appropriate speeds. The rows of slits are arranged at the different diameters so that the numbers of slits in each successive concentric ring are approximately proportional to the frequencies of the tempered scale. The tuning inaccuracies are, however, greater than 0·1 % in frequency, the normally acceptable limit [see Section 5(A)(*b*)]. In this particular arrangement one rotating disc carrying slits, together with its associated wave forms, is required for each octave. The optical arrangements utilized in this instrument are very compact and are indicated diagrammatically in Fig. 13. It will be seen that all the modulated light beams from all the notes of different tone colours of one octave are concentrated by the condenser lens on to one photocell, and the shuttering of the modulated beams of light associated with the individual notes is achieved by small electromagnetically operated shutters which operate at the focal point of the individual beams, so that

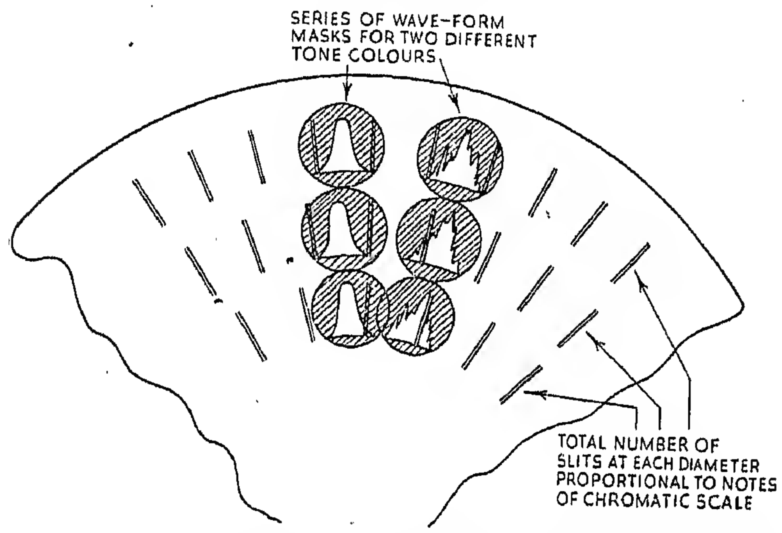


Fig. 12.—Sketch showing arrangement of stationary wave-form masks and slits on portion of rotating scanning disc of photo-electric organ.

the amount of movement required is extremely small. Eight such units are employed, one for each octave, so that eight photocells are required. The number of light sources used in this case is only four, because of the symmetrical disposition of the units on either side of the tungsten-filament lamps. The control of the many shutters from the console is carried out in a manner similar to that used in operating the pallets in pipe organs of the " unit " type.

The photo-electric organ constructed by Welte[38] employs a series of variable-area sound tracks arrranged concentrically on discs rotated synchronously at appropriate speeds. Small lamps illuminate the stationary scanning slits, and the resultant modulated light is concentrated on the photo-electric cells. The form of one scanning unit used in this instrument is shown in Fig. 14 (see Plate 1, facing page 532).

(ii) *Electromagnetic Generators.*

The electromagnetic system of generation was used by Cahill[39] in 1897, and it appears from his very complete and practical patent specification that he appreciated fully all the requirements for producing by synthesis musical notes of various tone colours. At that time the thermionic valve was not invented and he used large generators in order to obtain the requisite power. Contactors controlled from the console were used for mixing in appropriate proportions the alternating currents of sinusoidal wave form and various audio frequencies. He actually had this instrument constructed, and proposed to distribute the music over a telephone network, despite the limitations of such a means of translating the

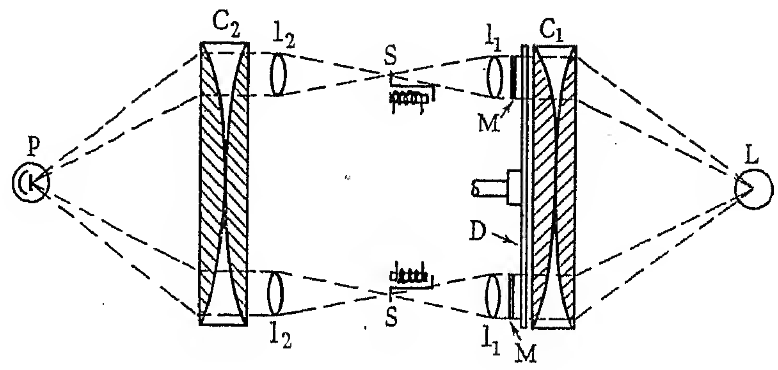


Fig. 13A.—Toulon's scanning unit.

L = light source.
C_1 = condenser lens producing approximately parallel light.
M = wave-form masks.
l_1 = small lenses for producing images of masks at l_2.
S = electromagnetically controlled shutters at focal points.
C_2 = condenser lens concentrating all beams on photocell P.

generated currents into musical sounds. The plant and control mechanisms occupied a very large room, and eventually the project failed for financial reasons.

It was not until after the invention of the thermionic valve and the development of amplifiers and loud-speakers that further proposals were made for developing this principle.[40] By means of valve amplification the use of very small generators was made practi-

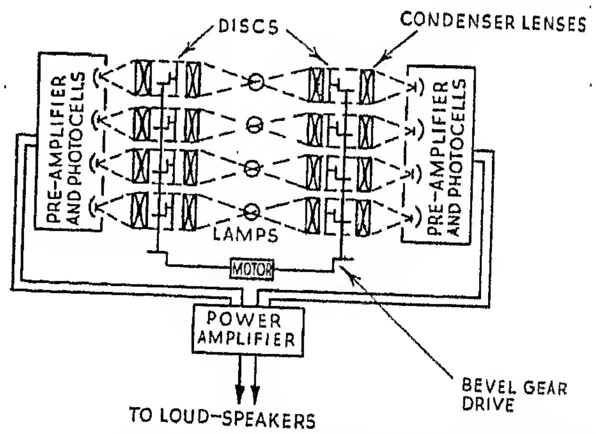


Fig. 13B.—Toulon's assembly of scanning units; one unit per octave.

cable, the simplest form consisting of a small iron disc with suitably shaped periphery mounted on a shaft and arranged to rotate in front of an electromagnetic pick-up. In early forms the pick-up was polarized electromagnetically, but in later designs the core is a permanent magnet. A unit of such a generator incorporated in a contemporary electronic organ developed by Hammond[41] is shown in Fig. 15. Rotation of the wheel produces an alternating current in the pick-up coil, corresponding approximately in wave form to the shape of the indentations on the wheel, and in frequency to the number of wave forms and speed of rotation. It will thus be seen that if a series of such generators are

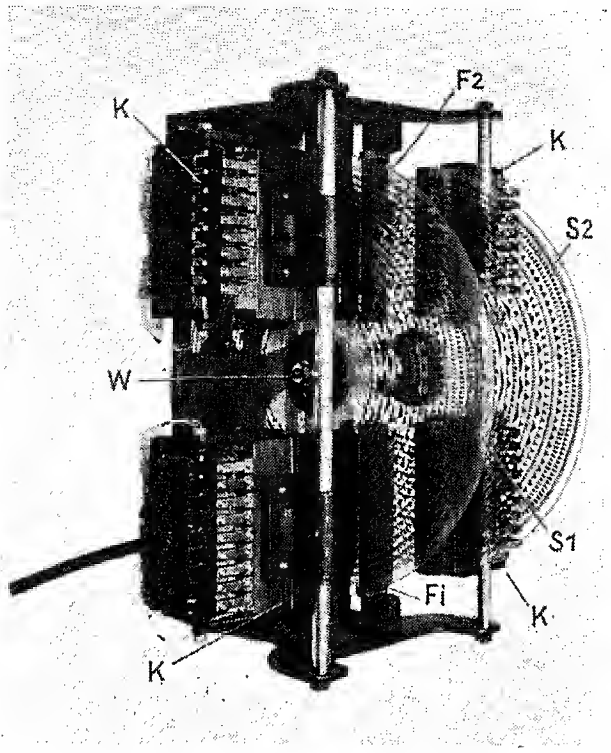


Fig. 14.—Welte photo-electric organ scanning unit.

W.—Spindle.
K.—Mechanism containing exciter lamps and shutters.
Fi and F2.—Photocells.
S1 and S2.—Discs carrying sound tracks.

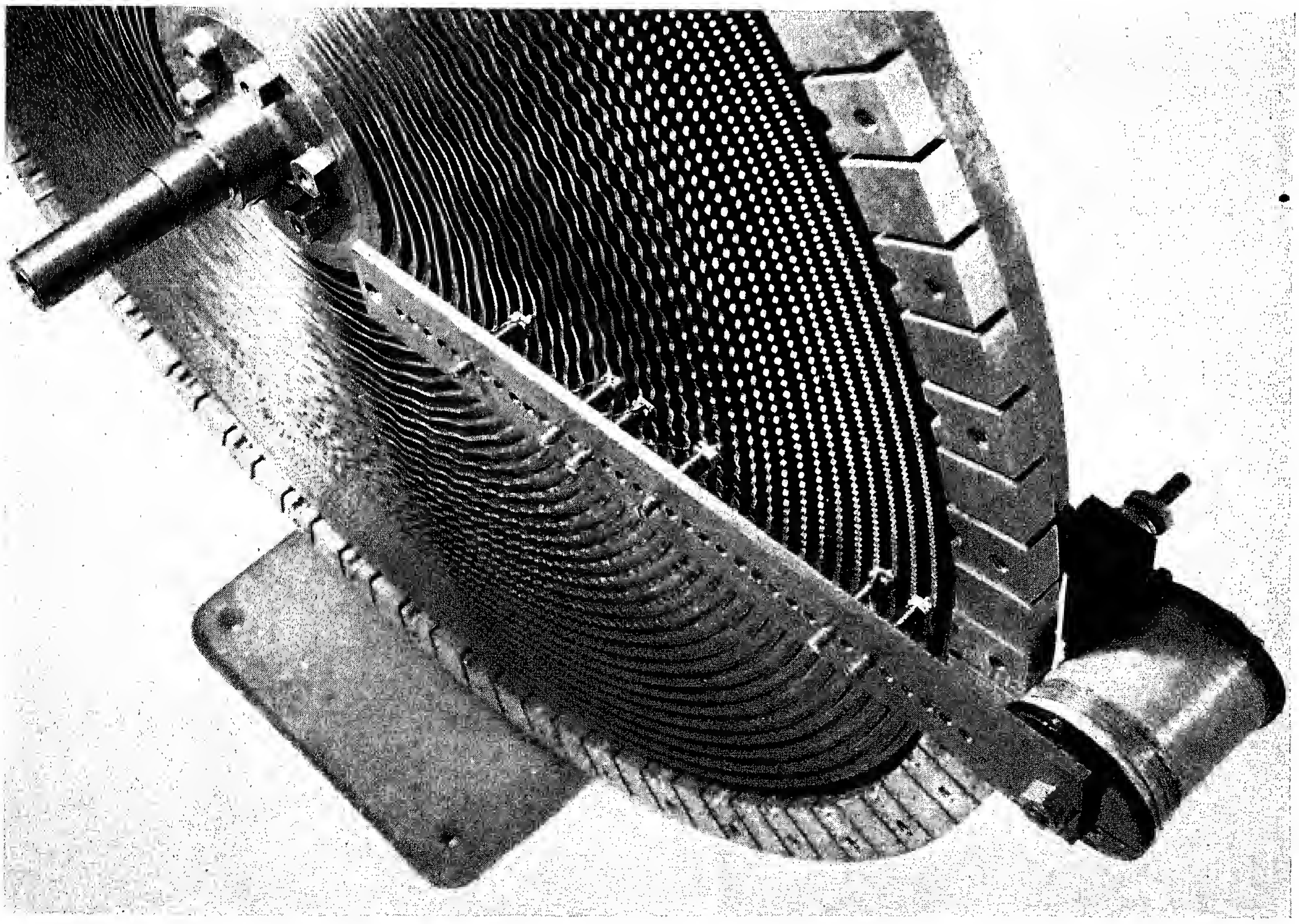


Fig. 16.—Partly assembled multi-frequency electromagnetic generator, showing portion of disc, and pick-ups on one radial arm.

(*Facing page* 532.)

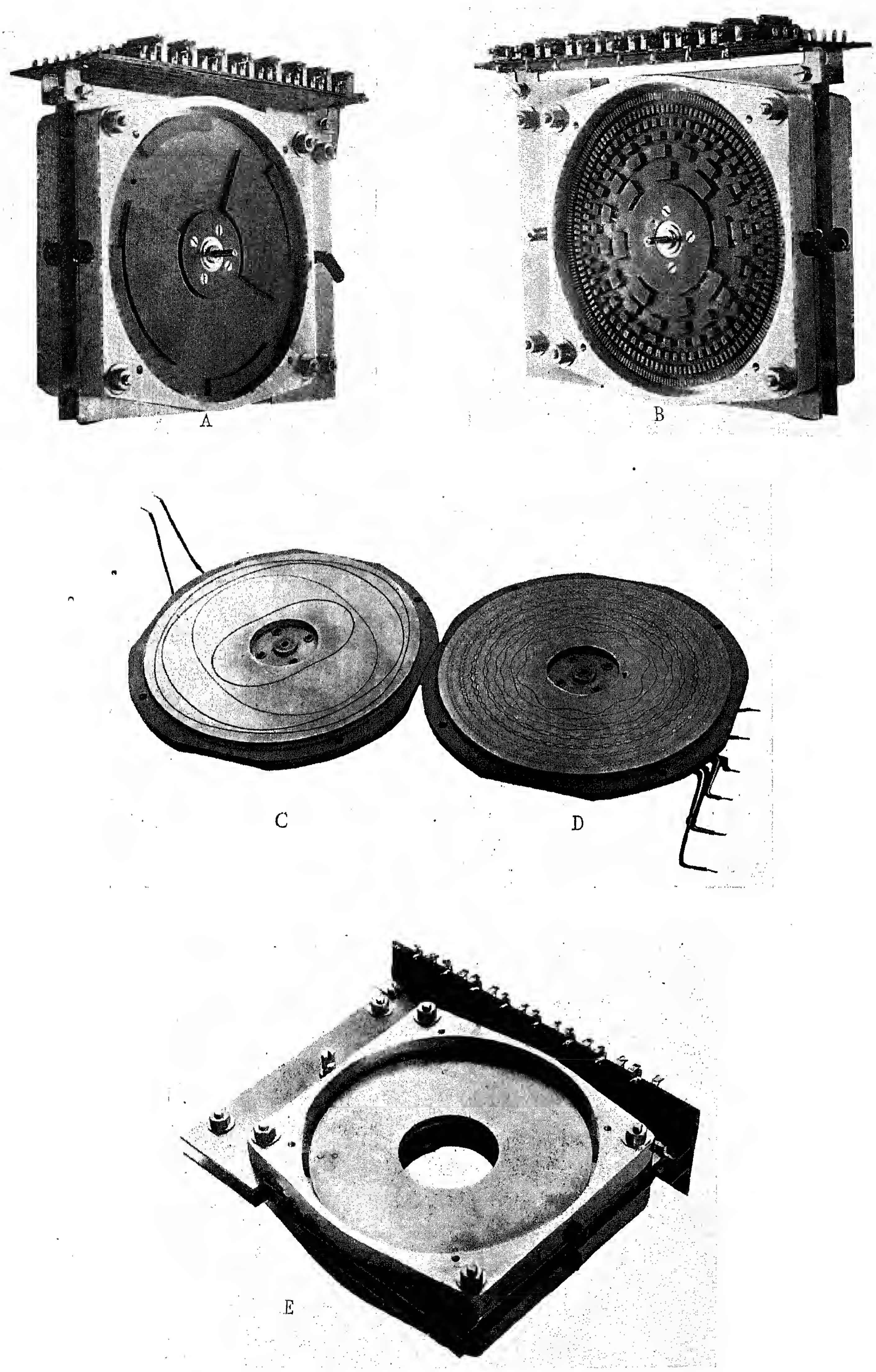
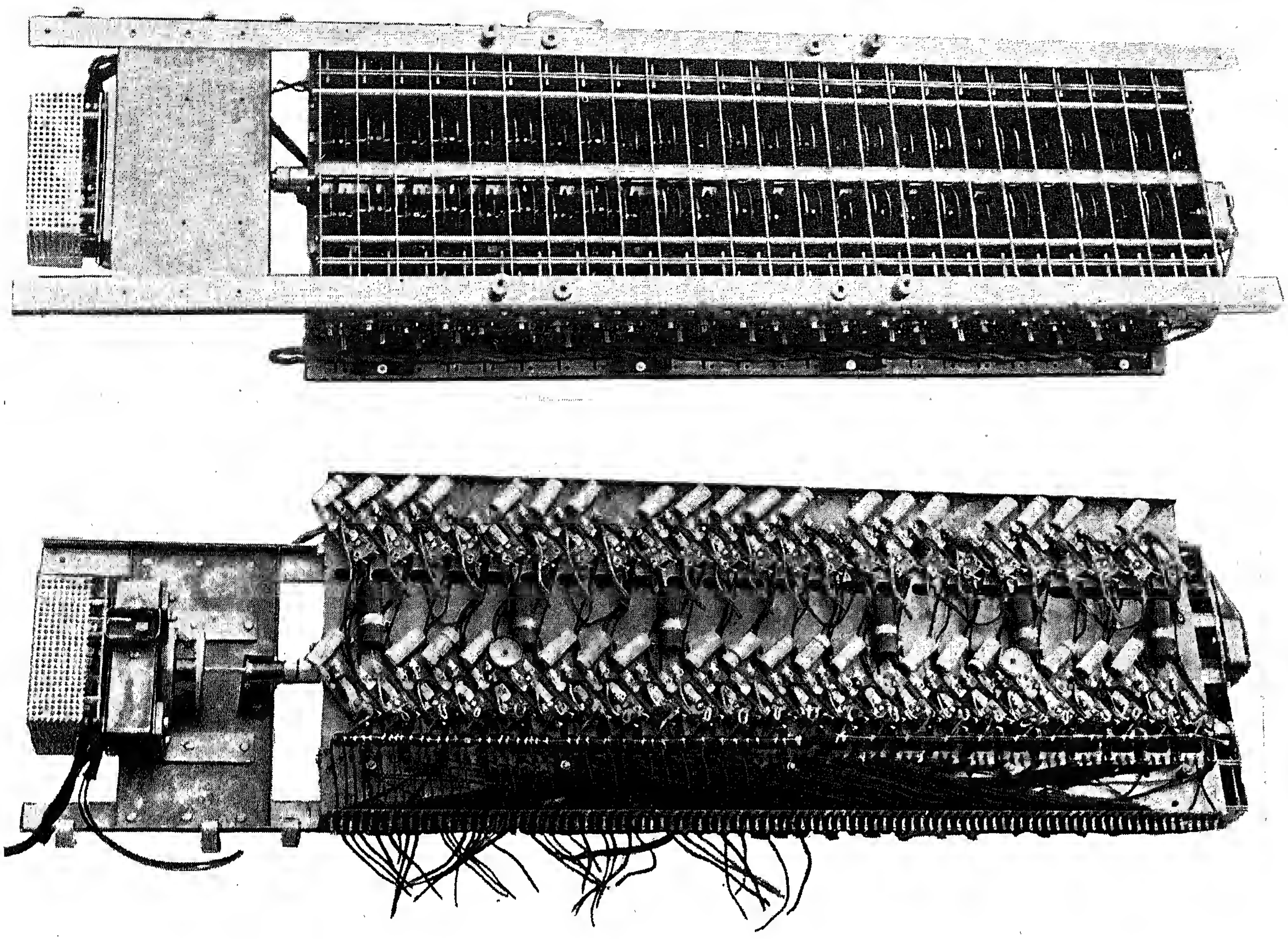


Fig. 21.—Electrostatic generator—partially assembled components.

A and B.—Bakelite rotors exposed. C and D.—Stators with sinusoidal contours. E.—Disc stator.



(*a*)

(*b*)

Fig. 22.—Assembly of 96-note electromagnetic generator.

(*a*) Alternator discs exposed.
(*b*) Mechanically damped synchronous drive (on left). Components of filter circuits (on right).

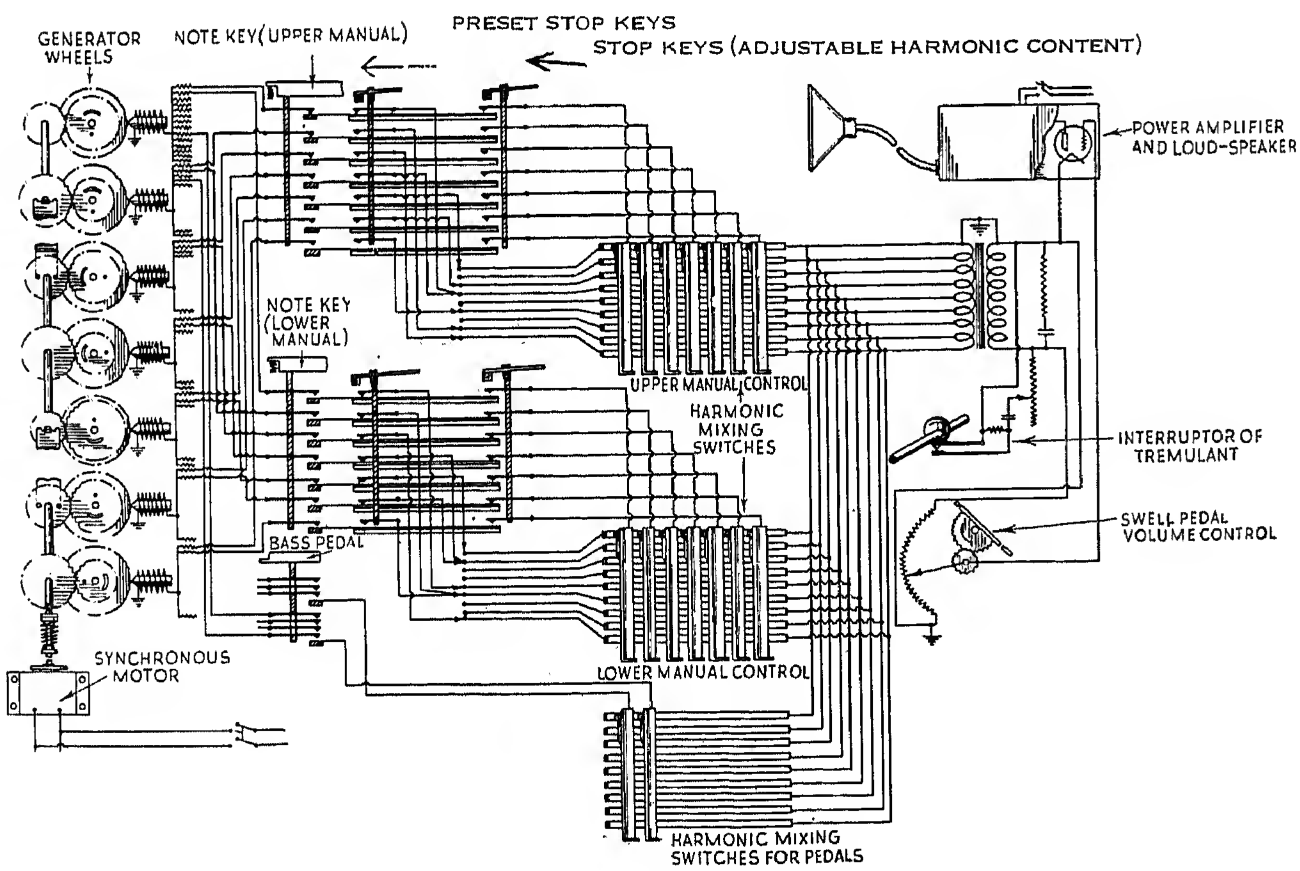


Fig. 23.—Form of circuit of an electronic organ utilizing electromagnetic generators of the type shown in Figs. 15 and 22.

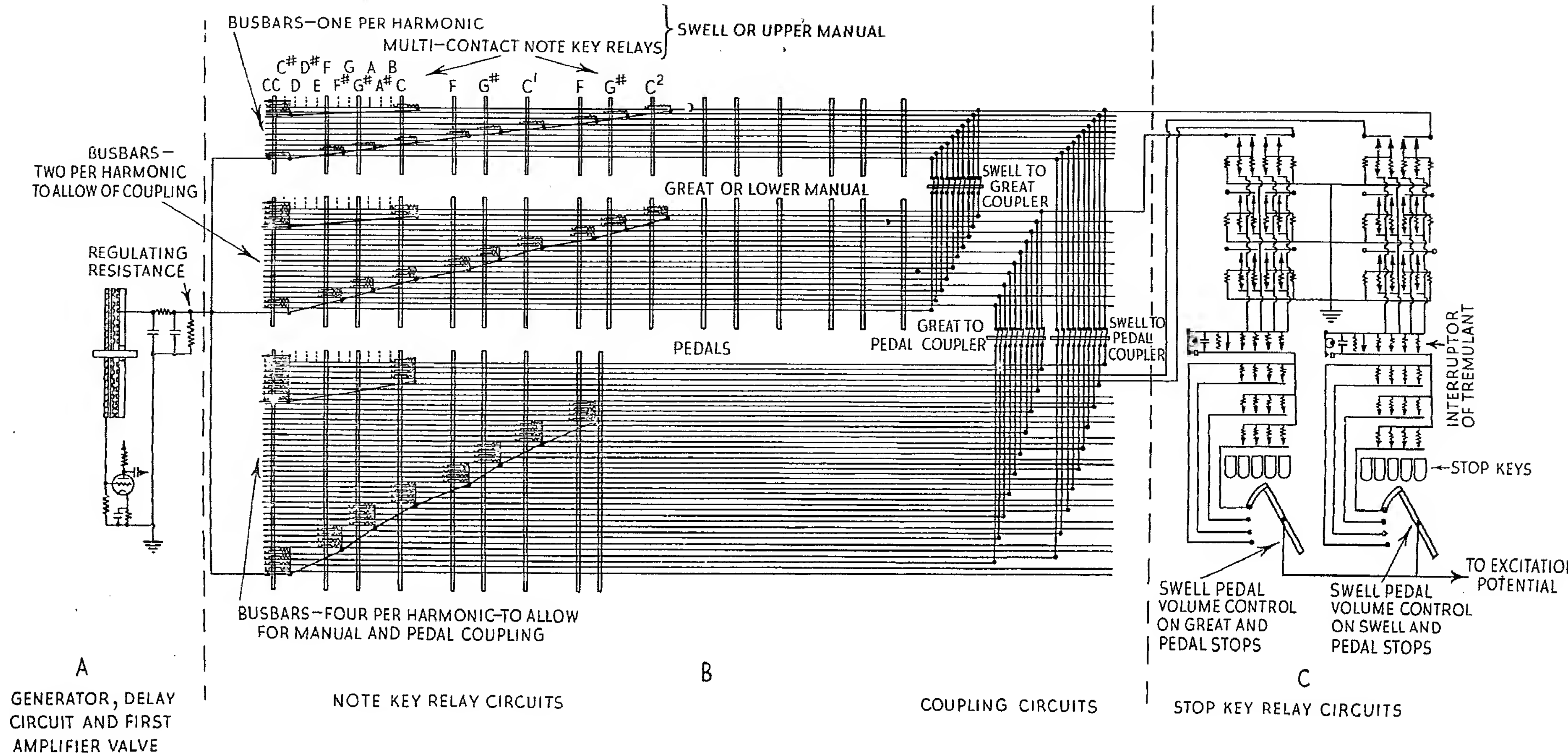
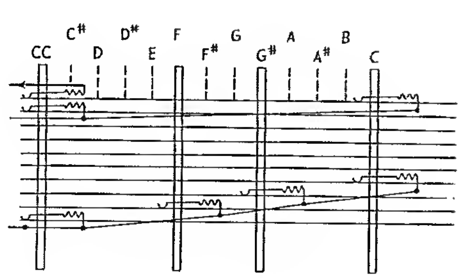


Fig. 24.—Form of circuit of an electronic organ utilizing electrostatic generators of the type shown in Fig. 21 (see Plate 2).



Enlarged view of note key relay shown in left-hand top corner of Fig. 24.

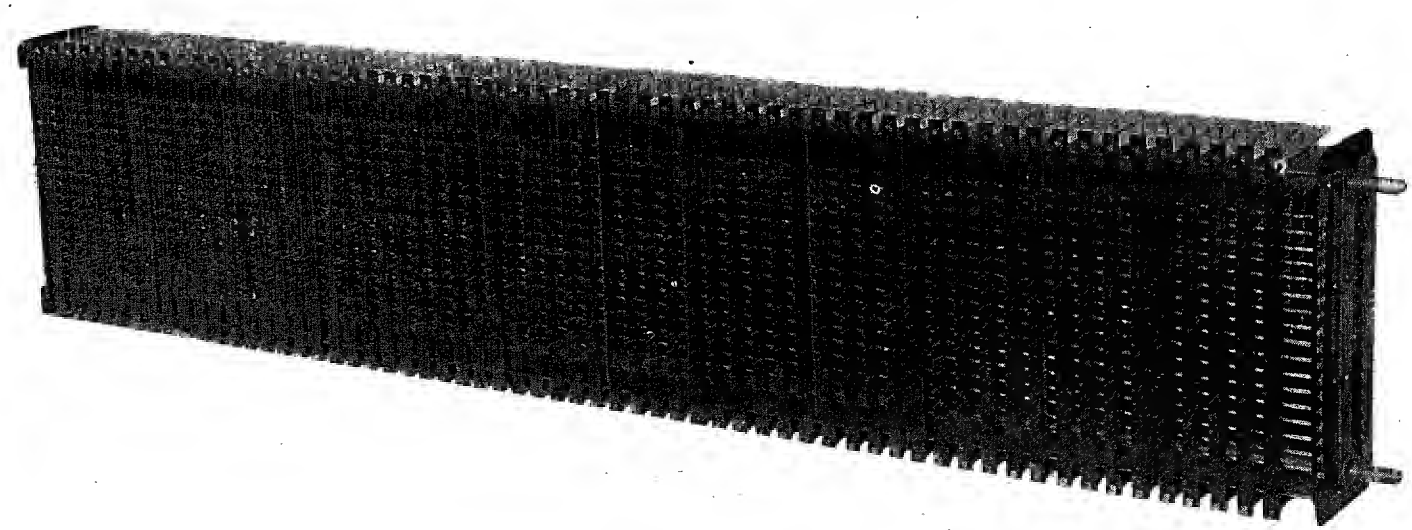


Fig. 25.—Assembly of 61-note key relays having 16 busbars—one per harmonic.

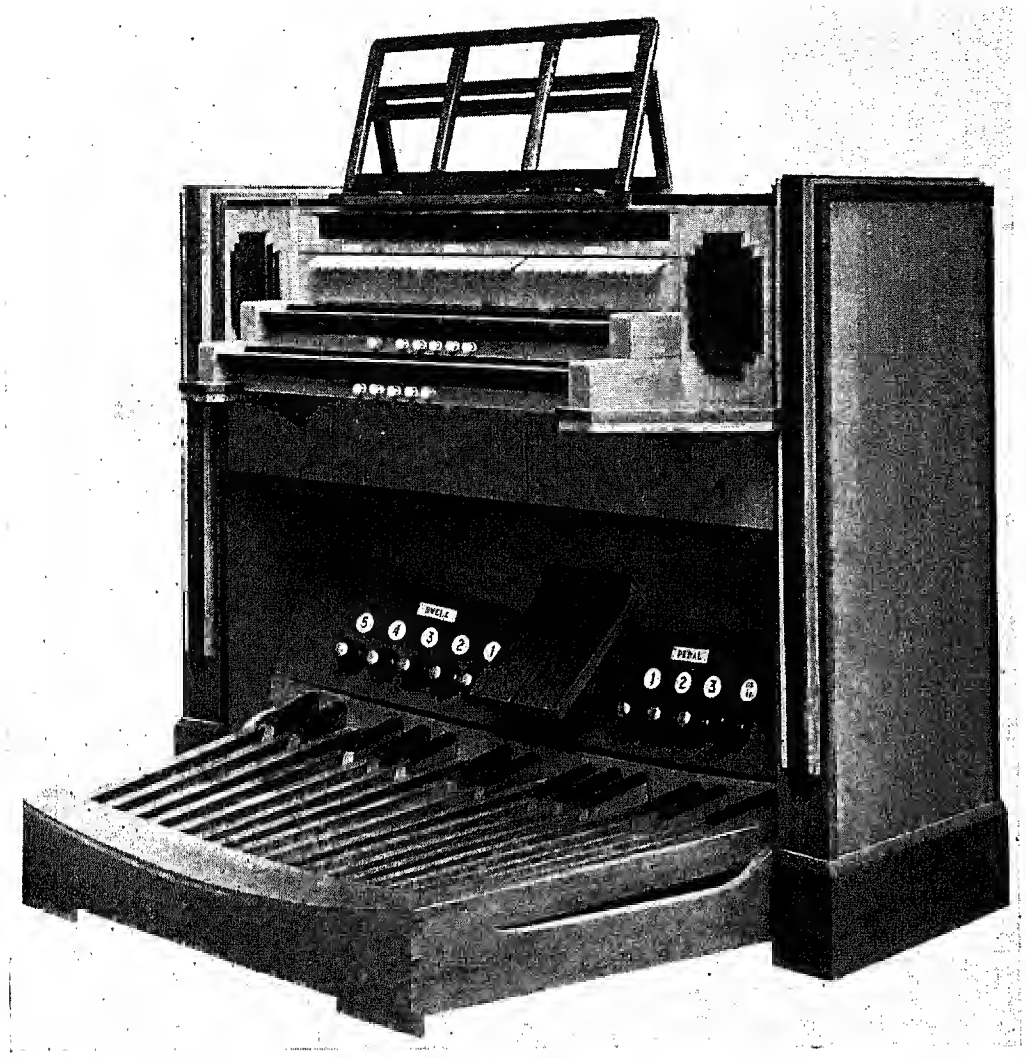


Fig. 26.—Complete electronic organ, incorporating electrostatic generators and circuits as in Figs. 21 and 24.

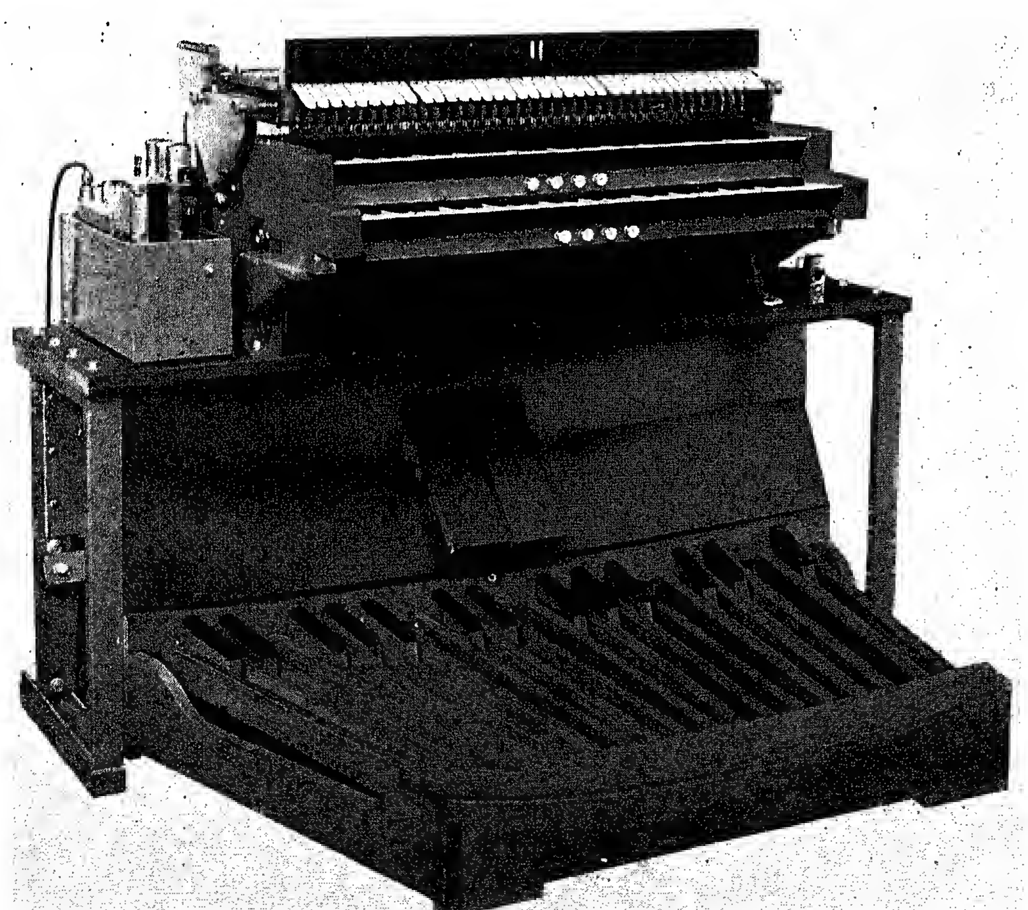


Fig. 27.—Electronic organ of Fig. 26, without case, and toe pistons.

Plate 6

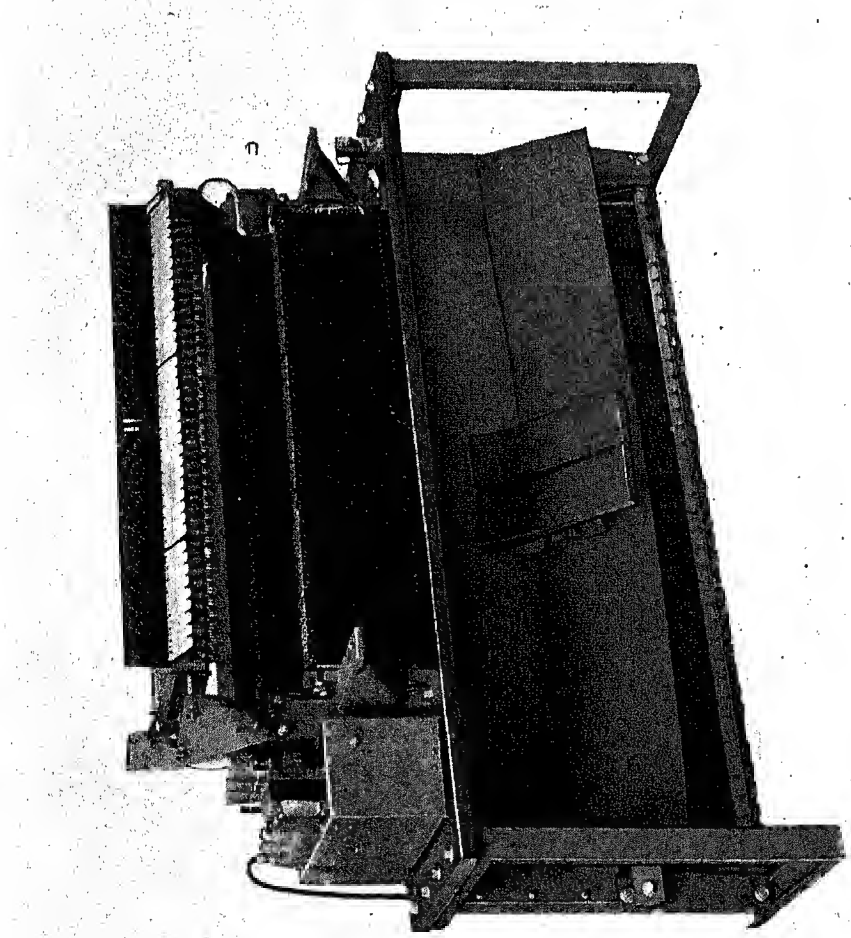


Fig. 28.—Electronic organ; as Fig. 27, but without keyboard and pedals, showing note key relays.

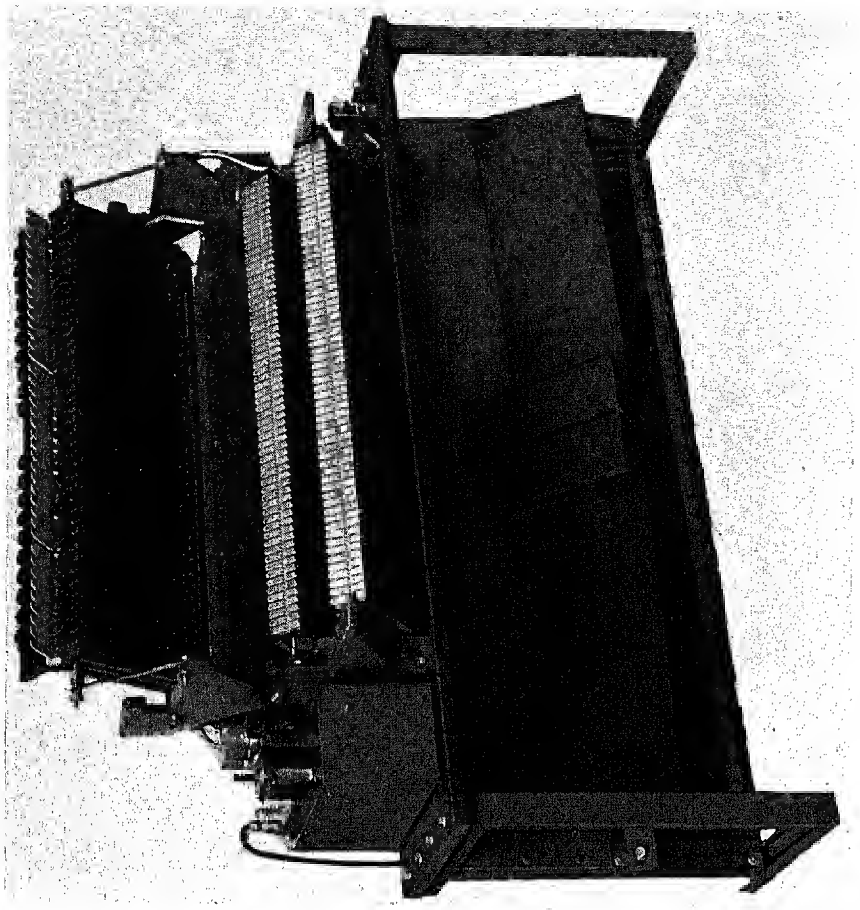


Fig. 29.—As Fig. [28, but with stop key relays raised and note key relays hinged forward.

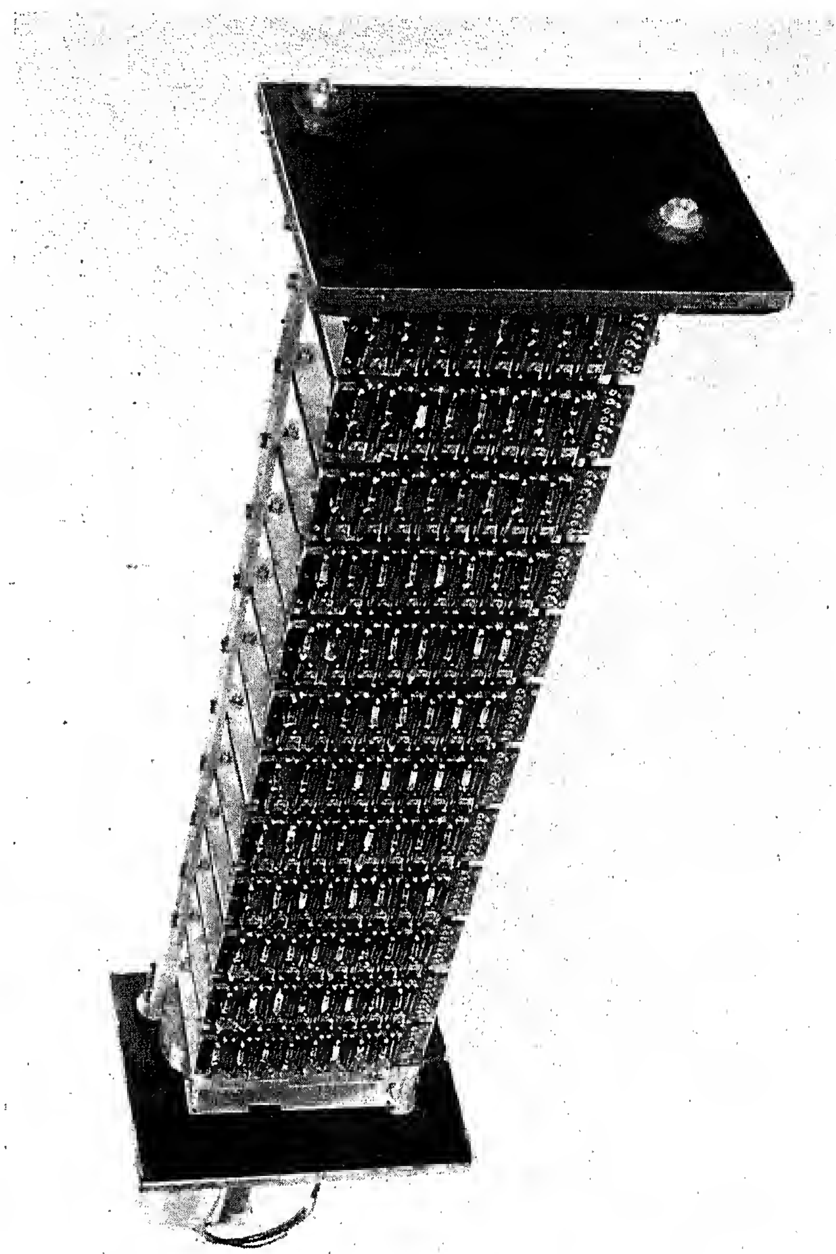


Fig. 30.—Electrostatic generators of organ in Fig. 26, showing unit assembly.

used, producing the fundamental and harmonic frequencies required, it should be possible to combine these currents of various frequencies in any desired proportions to produce various complex wave-forms. This form of generator is not only the simplest, but in practice it has proved the most economical, to construct. The electrical output from it is high as compared with that from electro-

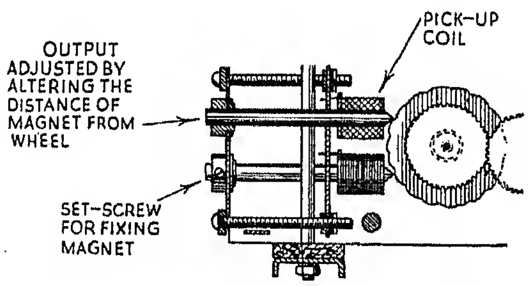


Fig. 15.—Electromagnetic generator; one disc per note; simple wave-form type.

static and photo-electric generators, and in consequence less amplification is required. In addition, the background noise level is low, and this, combined with the high output, enables a very quiet generator to be produced. A difficulty associated with this, and in fact all electromagnetic systems, is the elimination of fringing effects. This is of particular importance if sinusoidal wave forms are being generated, as spurious frequencies are introduced [see Section (5)(A)(*g*)]. This effect can be reduced to some extent by suitably shaping the pole-pieces or by the introduction of filter circuits to control the generated wave form.

In another form of generator which has been constructed experimentally,[42] a number of concentric ridges are cut on one face of a rotatable iron disc. On the face of each ridge, at right angles to the plane of the disc, sinusoidal wave forms are cut. The size and number of wave forms is so arranged that, progressing from the inner

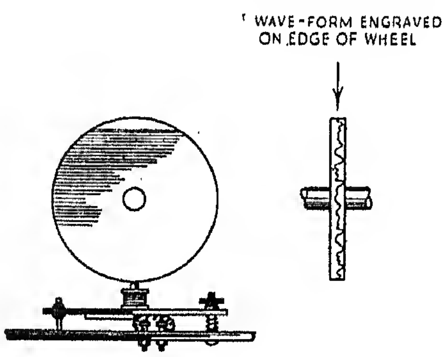


Fig. 17.—Electromagnetic generator. One disc per note—complex wave-form type.

ring, each successively larger ring has twice the number of wave forms of the inner adjacent ring. Series of magnetic pick-ups consisting of radially arranged iron strips with pole-pieces in the form of grub screws opposite each of the concentric rings, are set radially facing the side of the disc on which the wave forms are engraved, as shown in Fig. 16 (see Plate 1). It will be seen that by altering the relative distance of the screws in the pick-ups, chosen proportions of the frequencies generated when the disc is rotated may be obtained. Also, the magnitude of the current of complex wave form so generated may be controlled in each radial pick-up bar by varying the electromagnetic excitation. In an alternative arrangement the numbers of wave forms on successive generator rings may be proportional, within the allowable inaccuracies in tuning, to the semitone intervals of the equal-temperament scale.

Whilst this construction considerably reduces the number of moving parts, as compared with the single-note disc generators, it is more costly, and fringing effects are also present.

A further example of an electromagnetic generator developed by Robb[43] is indicated in Fig. 17. Here complex wave forms are engraved on the edge of the discs, the idea being to use one disc per note per tone colour, each disc generating, in its associated pick-up, current of the

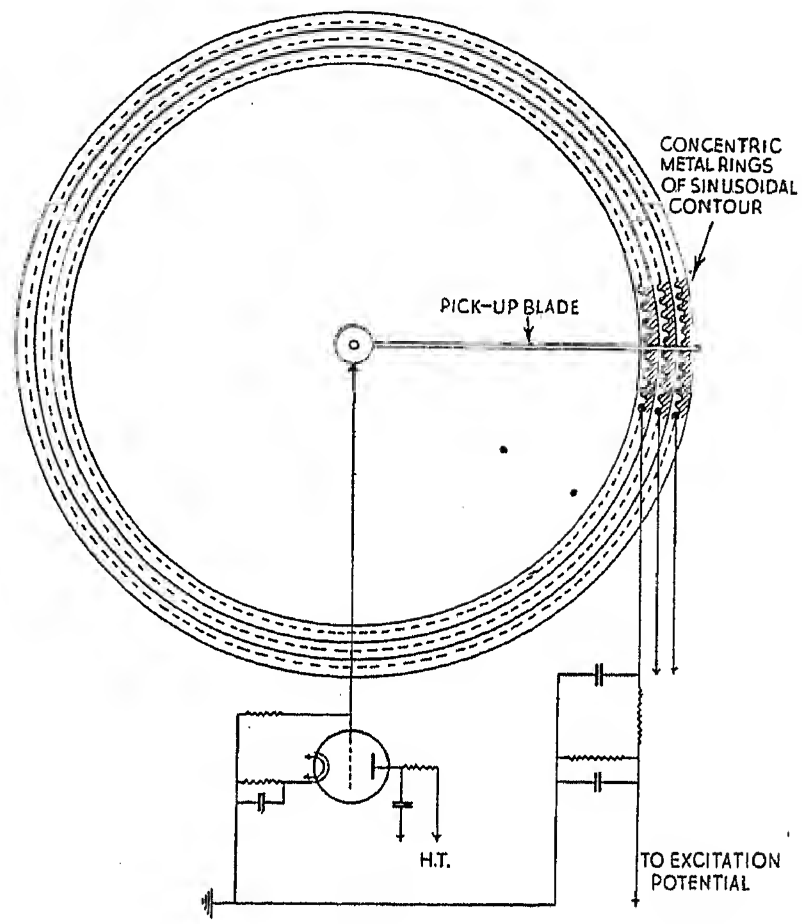


Fig. 18.—Electrostatic simple wave-form generator.

appropriate complex form. This system also suffers from fringing effects, and the construction has proved very costly.

(iii) *Electrostatic Generators.*

One early form of electrostatic generator, due to Bourn,[44] is shown diagrammatically in Fig. 18. This comprises a stationary disc of insulating material on which are arranged concentrically a series of metallic rings, one edge of which is of sinusoidal form. A flat metal arm mounted at right angles to the plane of the disc, with one edge about $\frac{1}{64}$ in. away from it, rotates over the disc about its own centre. The rotating arm and the sinusoidally shaped rings form a capacitance varying cyclically in a manner depending on the speed of rotation and the number and shape of the wave-forms on the metal rings. By connecting these elements in the circuit shown in the Figure, small voltages of sinusoidal wave form are generated when any one ring is keyed into the

excitation circuit. If more than one ring is keyed into circuit at the same time, a voltage will be generated, having two or more component frequencies superposed in proportions depending on the values of the excitation potentials. By suitable choice of these excitation potentials, a chosen complex voltage wave-form may be generated.

The output of such a generator is very small and is liable to be uneven due to mechanical difficulties in maintaining accurately the distance between the rotating metal arm and the stator. Very small mechanical errors may in consequence introduce very objectionable cyclic modulation of the output. Also, fringing troubles will arise from this form of construction, and the generation of sinusoidal wave forms will only be approximated.

These difficulties are overcome by making the rotor of the web form shown in Fig. 19, and the stator as in Fig. 21(*d*) (see Plate 2). Here, the number of radial lines or scanning elements has been increased[45] so that they are spaced $\frac{1}{2}$ wavelength from one another. This results in an appropriate increase in output and also provides a compensation effect, should the scanning

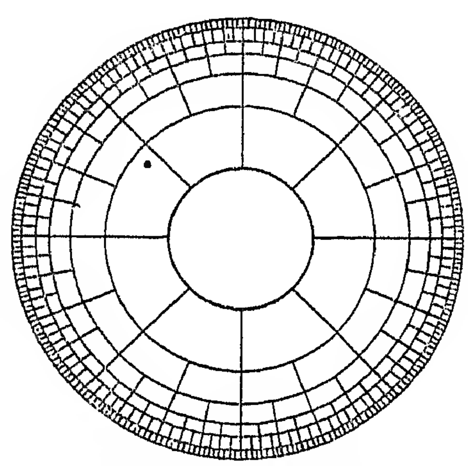


Fig. 19.—Web form of rotor with multiple scanning elements.

disc run out of truth owing to small mechanical inaccuracies of mounting. By forming the rings from metal, sputtered on to an insulating base, and afterwards engraving the concentric sinusoidal contours, an island is left between each ring. If this island is connected to earth, fringing is prevented by reason of the resulting focusing effect of the lines of force. The circuit arrangements in Fig. 18 entail the use of a brush-type contact between the rotating collecting arm or multiple scanning elements and the grid circuit of the first amplifying valve.

In the circuit arrangement[46] in Fig. 20, the brush connection is in the earthed side to overcome the possibility of noise being generated owing to this moving contact.

A method of still further increasing the output consists in making the scanning elements in the form of segmented areas covering half the corresponding wavelength.[47]

In systems where the rotor and stator are placed close together, stray leakage currents, giving rise to noise, may be generated as the result of the presence of small particles of dust or moisture.

The above effects are minimized in a later form of generator construction[48] shown in Fig. 21 (Plate 2). This avoids the need for moving contacts, and allows of the use of larger spacing between the electrodes, thus reducing the mechanical and electrical difficulties.

In this arrangement the bakelite rotors are of the form shown at A and B in the photograph of the partly assembled generator. The corresponding stators for this generator are shown at C and D, respectively, whilst the plane disc form of stator E fits on the opposite side of the rotors in both generators. In this construction the bakelite rotors produce sinusoidal variations in the dielectric between the corresponding concentric conducting rings of sinusoidal contour on the stators, and the stator discs. For example, a complete generator for providing two low frequencies consists of a rotor such as A, revolving between a stator C and a disc E. By connecting the conducting rings on one stator C to the appropriate excitation potentials through suitable resistances and switching circuits, and the other stator disc E to the grid circuit of the amplifier, voltages of sinusoidal wave form may be generated.

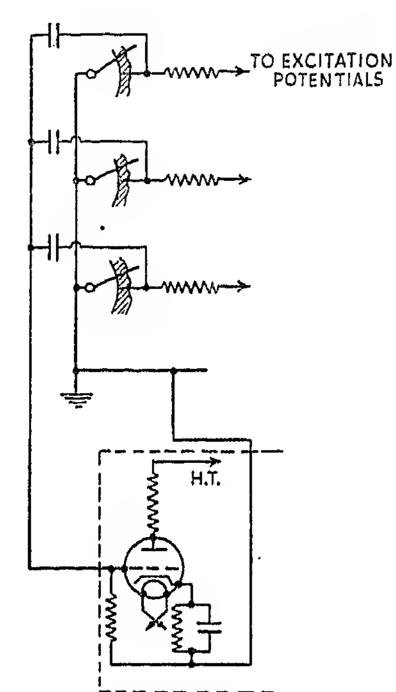


Fig. 20.—Circuit arrangement for electrostatic generator with brush connection in earthed lead.

Systems have also been proposed by Curtis, Estell Scott and Biggs involving the use of electrostatic generators to modulate the high-frequency currents produced by valve oscillators.[49] Subsequently, the modulated high frequency is passed through a detector stage, and the audio-frequency component amplified. The advantages claimed for this system are that the construction of the rotary generator is extremely simple, the signal/noise ratio practically infinite, and amplification problems simplified. As keying and mixing of high frequencies can be accomplished through small condensers, it is proposed to use such methods to avoid key contacts and mixing circuits. By using different high-frequency carriers, the frequencies for several manuals could be supplied from the one rotary generator, via suitable filter circuits. The possible disadvantage of this arrangement is the danger of mutual and radio interference, and although it is claimed that this could be rendered innocuous by adequate shielding, the authors are not aware of any full-compass organ which has been constructed on this principle. It is

believed that this system has not passed the very early experimental stage.

(C) Frequency Generators—Mechanical Considerations

(a) Generators other than Rotary Forms.

The non-rotary forms of generator classified under sub-groups (C) (*a*), (*b*), (*c*), (*d*), and (*e*) of Table 3 involve no particular mechanical problems, and in all cases key-boards, consoles, and methods of control, follow normal pipe-organ practice.

(b) Rotary Generators.

In the case of rotary forms of generator there are many mechanical problems to be surmounted, foremost among these being that of providing the accurately constant-speed drive to the various rotors.

In all rotary systems, whether photo-electric, electro-magnetic, or electrostatic, the accuracy of pitch depends on the accuracy of rotation of the generator rotor. According to the particular system employed, one of two general forms of drive will be necessary.

Where all the 12 semitones within the octave are derived from one disc, cylinder, or group of generator rotors on one shaft, each successive shaft will need to be driven at twice the speed of that providing the frequencies for the octave below, so that the gear ratios in this case are simple ones. The accuracy of the musical pitch will obviously depend on the number of scanning elements or generator poles provided for generating each semitone, and on the constancy and actual speed of the rotational drive. For example, to take the case of a photo-electric scanning disc provided with slits radially engraved one fundamental wavelength apart in concentric rings, clearly if the intervals are to be those of the tempered scale to within $0 \cdot 1$ % [see Section 5(A)(*b*)] it will not be possible to use less than a predetermined number of slits in each ring. This will automatically determine the actual speed of rotation of the disc for a given musical pitch.

In the alternative form, the fundamental frequency and all its harmonics are derived from one disc, cylinder, or group of separate note generators all carried on one shaft. The semitones are provided by driving 12 such generators, or sets of generators, at speeds progressively increasing in the ratio $1:\sqrt[12]{2}$. The accuracy of the pitch of the semitone intervals will therefore be governed by the gear ratios employed.

Even if precision-made clock gears are used in the drive from the synchronous motor, irregularities in speed will occur, resulting in frequency variations in the notes produced which will be intolerable to the ear. However, it has been found that by the use of carefully designed mechanical filters these speed variations can be damped out.

One example of a 96-note electromagnetic generator[50] is shown in Fig. 22 (see Plate 3). The upper picture shows the many generator wheels and their associated magnets, whilst in the lower view the synchronous-motor drive with its mechanical filters can be seen on the left. On the top of the generator housing are the components of the electrical filter circuits, previously referred to, which are necessary in order to eliminate the unwanted harmonics in the generated currents, the wave form of which is only approximately sinusoidal. The mechanical filter in the drive will be seen adjacent to the synchronous motor. This comprises a spring-driven flywheel to reduce hunting, followed by a spring drive to the first counter shaft on which is mounted the driving gears for the first set of rotors. The drive to the rotors is then taken via a small hair-spring so that any non-uniformity due to back-lash or imperfections in the gears is damped. In this manner the necessary constancy of speed is maintained. It is interesting to note that the hair-spring drive to the rotors also considerably reduces the generation of impulse voltages due to the backlash in the teeth of the gear wheels, this being possible by reason of the following facts: the voltage generated is proportional to the rate of change of motion of the rotors, which in turn is proportional to the rate of change of the force acting upon the teeth of the gear wheels. This force is, of course, a product of the backlash in the teeth.

As these generators are usually housed in the organ console, the small self-starting synchronous motors used must be practically silent. In fact all vibration of the generator mechanism must be reduced to a minimum as it gives rise to background noise in the amplifier and loud-speaker system.

In electrostatic generators microphonic noise can arise from extremely small relative movements of the generator components. In consequence, those parts liable to vibrate need to be damped, or preferably a form of construction adopted in which this trouble is eliminated. This can be achieved by moulding the components. The choice of gearing and shaft diameters is also of importance and it has been found in practice that the use of small diameters assists in reducing noise. Actually, this results in a cheaper form of construction since the shafts can be made from the ground steel rod available in small diameters in the trade.

(D) Mixing Circuits

In the various generating systems, methods must be devised for combining the many frequencies generated, and in this connection, as stressed in Section 5(A)(*g*), it is necessary to take into account the relation between the sensation of loudness at different frequencies and the radiation intensity.

In considering the circuit arrangements for producing equal steps in loudness of the tones produced, the energy steps must be in geometrical ratio in accordance with Weber's law which states that "Equal increments in intensity of sound as interpreted by the ear are increments which bear a definite relationship to the intensity of sound before the increment."

In addition it may be well to bear in mind that when considering the circuit arrangements for producing a given summation of energies, the voltages or currents involved must be proportional to the summation of the square root of the energies. The importance of this is to ensure that:—

(i) When more than one note of the same tone colour is played at a time the loudness of the individual notes is not different from that when notes are played singly.

(ii) When several individual tone colours are played simultaneously by the addition of stops, the resultant

combination tone shall truly represent the addition of the tone colours and loudness, as when stops are added in a pipe organ.

The methods of mixing fall into three general groups as follow:—

(a) Addition of Modulated Light by Photocell.

In the light scanning methods used in photo-electric types of organ, the problem of mixing is an optical one. The components of the many individual scanning elements must be so arranged that the modulated light beams are all collected on to one photocell or a small group of photocells. Many methods have been proposed, and Fig. 13, which has already been referred to, is an arrangement used by Toulon,[51] requiring one photocell per octave, i.e. 8 photocells in all. These photocells are connected in a parallel network and thence to the input circuit of a power amplifier and loud-speakers. In another example, used by one of the authors[52] in an experimental instrument, again all the scanning slits for the 12 semitones within the octave were carried on one disc. The parallel light, either from groups of single-note projectors or a small number of multiple-note projectors, was in this case passed through the wave masks and scanning discs to one or more large parabolic mirrors, which focused the modulated light beams on to one or more photocells.

(b) Addition of Audio-Frequency Components.

In general, in the generator systems classified under (C) (*a*), (*b*), (*d*), (*e*), and (*f*)(ii) in Table 3, in which either complex or sinusoidal wave-form audio frequencies are generated and subsequently combined, some form of mixing circuit must be provided.

In complex wave-form systems this is accomplished by arranging for the outputs of the various generators to be fed to multi-ratio transformers, the feeds from the generators for each particular tone colour being provided with limiting impedances in order to keep the primary loading on the transformer as constant as possible. If this is not done, frequency distortion will occur according to the number of notes being played. A similar circuit arrangement is required for combining the various note frequencies associated with their respective stops as they are brought into action. In these systems this is very difficult to achieve. Approximations to the ideal additive requirements are usually employed in attempts to simulate the progressive increase in loudness which occurs in pipe organs when many notes and stops are played simultaneously.

As one example of a *simple* wave-form generator, Fig. 23 (Plate 3) indicates the complete circuit of an organ incorporating the 96-note, simple wave-form tempered-harmonic generator of the single-note-per-disc, magnetic type. By means of the multi-contact key switches the current from the note-frequency generators is fed via a limiting resistance to the stop switches, which are adjustable over the busbars connected to the 8 tappings on the primary of the output transformer, which feeds the power amplifier. The tappings of the transformer primary are such that the successive tappings provide voltages in geometrical progression. This is in order that adjustment of the harmonic mixing switches which make contact on these busbars shall provide successive equal increments in loudness, in accordance with Weber's law. Each of the harmonics of one note is obtained via a limiting resistance from the appropriate generator through one of the contacts of the key switch to the appropriate harmonic mixing switches. The resistances in each circuit are high in value compared with that of the generators in order to avoid appreciable voltage-drop when the many circuits are paralleled.

It will be clear that the depression of a key switch will connect to the transformer the generators supplying frequencies which have been selected by the harmonic mixing switches, the intensity of the particular harmonics being regulated by the extent to which the mixing switch is drawn and the particular busbar which has been connected in this manner.

Additional multi-contact stop switches are provided so that any harmonic content which, by experiment with the harmonic mixing switches, has been found pleasing, can be connected to the appropriate tappings of the output transformer. Depression of one of these stop keys can then be made to produce the same result as setting up a particular harmonic combination on the mixing switches. For convenience in playing the instrument, several such switches are provided for each manual, and so arranged that depression of one releases any other which may previously have been in operation. It is not possible in this arrangement to add the tone colours of the individual stops as in a pipe organ.

A very simple means of adjustment is provided for ensuring that the output of all note-frequency generators throughout the compass of the instrument can be set so that the loudness of the resultant notes is uniform. This is accomplished by adjusting the distance from the tone wheel of the magnet carrying the pick-up coil. The means provided for accomplishing this adjustment are indicated in Fig. 15. Of course, a progressive increase or decrease in loudness throughout the frequency range can be made with equal facility, if required, and in all cases it is easy to avoid the non-uniformity in loudness of successive notes which might otherwise arise due to the circuit, and in particular the loud-speaker frequency characteristic.

In order to reduce " key clicks " and the influence of spurious high harmonics arising from magnetic fringing effects in the generators, a resistance-capacitance network is placed across the output of the transformer.

This system does not provide means for regulating the envelope of sound waves produced, other than in a general manner by the skilled manipulation of the adjustable potentiometer in the secondary side of the output transformer, which is operated by a swell pedal as in normal pipe-organ practice. A tremolo, adjustable for frequency, is produced by a motor-driven interrupter system associated with a resistance-capacitance network, also across the secondary of the transformer.

(c) Addition by Control of Excitation Potentials in Electrostatic Generators.

The mixing circuits which will now be described are used in conjunction with electrostatic rotary generators, and in modified forms in other types of electrostatic generator. In such generators the a.c. output, and therefore, the voltage impressed on the grid of the first

amplifier valve, will be proportional to the d.c. excitation voltage applied to the generator electrodes. The generation of sinusoidal or complex voltage wave-forms of the required magnitudes is therefore most readily performed by applying the appropriate d.c. voltages to the generators.

A circuit diagram indicating the method of operation and control of the generator excitation in one example of an electronic organ operating on this principle is shown in Fig. 24 (Plate 4). This figure is divided into three sections. A is the generator and circuit for controlling the starting and stopping time or envelope shape of the notes produced. This enables the comparatively slow speech associated with organ tones, or alternatively percussive and other special effects including bell and xylophone tones,[53] to be imitated. By the same means the undesirable transients, which occur on the closing of the many circuits operated by the note keys, can be eliminated, thereby avoiding " key clicks."

The note key relay circuits shown at B in the Figure enable the required excitation potentials to be applied to the generator. One set of note key relays is shown in Fig. 25 (Plate 4). The application of the required excitation potentials to the appropriate generator rings is accomplished by providing one limiting resistance in series with each note key switch contact. For any one note of the scale, the depression of the note key moves one of the vertical tracer bars which operate the multi-contact note key switches, and connects them with the appropriate busbars. The number of busbars required depends on the number of harmonics which will be utilized in synthesizing the tone. In the circuit diagram, Fig. 24, it will be noted that only 10 busbars and multiples of 10 are shown. This is only to simplify the drawing, but in the actual instrument, as will be seen from the photograph of the unit in Fig. 25, 16 busbars are used for the 16 harmonics. It should be observed that, as the harmonics are derived from the 96 notes of the tempered scale, the number available for the higher notes becomes progressively less. It will be clear from the circuit diagram that each frequency generator ring is connected through the appropriate resistances to a number of note switch contacts. For example, the generator ring producing the frequency of the note C^2 is connected to a switch contact operated by tracer bar C^2, which is moved by the note key of that name.

This allows the generation of a voltage of sinusoidal form when the key is depressed, so that a pure note of correct pitch will be sounded, providing the busbar has been connected to an exciting potential by the operation of a stop key switch. But it will also be seen that the same generator ring is connected to contacts operated by the tracer bars of all note keys having a fundamental pitch such that the frequency C^2 is one of the first 16 harmonics. Each frequency generator ring is connected in a similar manner to note key switch contacts corresponding to the note of the generated frequency and also the other notes of which the generated frequency is one of their harmonics. When, therefore, an excitation potential is applied to one busbar by a stop key relay, shown at C in Fig. 24, and a note key depressed, an excitation potential will be applied to one generator ring. Should the stop key relay only excite the busbar which makes contact with the generator rings providing frequencies corresponding to the fundamentals of the note keys, then when note keys are depressed only fundamental tone will be generated. Different stop keys can be arranged to excite different busbars or combinations of busbars in any desired manner so that depression of a note key will then result in the generation of a note, not only of fundamental pitch but having any required number and proportion of the available harmonics. The correct proportioning of the limiting resistances in series with each note key and stop key contact ensures that the simultaneous depression of more than one note and/or stop key will produce the correct additive effect in the resultant musical notes.

It will be seen that if the note key resistances were of a very low value, the busbars would virtually be short-circuited. Alternatively, if they were all of very high value, the potential across the regulating resistance, shown in section A of the circuit diagram, would be very small and not in proportion to the energies necessary to produce, in accordance with Weber's law, the correct loudness increments. It has been found in practice that, provided the regulating resistance is between one-third to one-fifth of that of the key resistances, then the correct additive effect will be obtained within the limits tolerable to the ear.

The charging or excitation potentials applied by the stop keys must be proportional to the summation of the square root of the energy levels at which the several frequencies are required either as fundamentals or harmonics, to produce the required tone colours. The correct proportioning of the stop key resistances connected to the negative side of the d.c. excitation supply determines the actual potentials applied, and the accuracy with which the tone colours, singly or in combination, are produced.

Space will not permit of the treatment of methods of calculating the values of these resistances and those regulating the loudness, as controlled by the swell pedal which operates by varying the busbar excitation potentials. For further details, therefore, reference should be made to the appropriate patent specifications.[54] This method of regulating the loudness is used in preference to gain controls on the power amplifier, as it avoids the increase in background noise with increasing loudness, and enables the groups of stops on the individual keyboards and pedal board to be separately controlled for loudness, by means of separate swell pedals, varying independently the potentials applied to the busbars of the respective keyboards and pedal board. Also, by suitable proportioning of the stop-key volume-control resistance values, it can be arranged that, in all or some stops, the higher harmonics increase in loudness progressively as loudness is increased by operation of the swell pedal. This simulates the effect produced by the swell box in a pipe organ (see Sections 2B and 2C).

The double set of busbars and note key contacts associated with the lower or " great " manual are necessary in order that when the " swell to great " multiple contact switch, shown in the diagram, is closed, notes played on the " great " will be coupled to notes of the same name on the " swell." Similarly, the four sets of busbars associated with the pedal board are required to produce the " great to pedal " and " swell to pedal " coupling effects,

which, together with the " swell to great " coupling, are required in pipe-organ playing technique. These three couplers are operated by the three multiple-contact switches, which can be brought into action by the appropriately marked stop key switches on the console. The tremulant effect is produced by the cam-driven interrupter shown in section C of the circuit diagram, and is also brought into operation by a stop key switch.

Thus it will be seen that in this system the mixing circuits are so designed that a sensibly true additive effect, both of notes and stops, is obtained as in a pipe organ, together with manual and pedal coupling facilities and independent control of loudness of manuals and pedals by separate swell pedals.

(E) Sound-Producing Equipment

Considerable progress has been made in the design of amplifiers and loud-speakers in recent years, particularly in connection with sound-film developments. The quality of reproduction has made steady advances, and very great acoustical outputs can now be obtained as the result of new and more efficient designs of amplifier and loud-speaker. Therefore, it is not proposed to deal at length with this subject.

It is interesting to note, however, that although the requirements for sound-producing equipment to be used in electronic organs involve problems peculiar to this particular application, the design of special sound-producing systems for this purpose has received comparatively little attention.

As has been stressed earlier, in a number of the systems used in electronic organs, irregularities in the frequency-response curve of the amplifier and loud-speaker system can be compensated in some measure by adjustment of the output of the individual frequency generators. In such systems, therefore, very uniform frequency-response characteristics are not essential, although obviously in types of generator where the output of the individual note frequencies is not adjustable, a uniform frequency-response will be necessary.

The main difficulties arise in the extension of the frequency range down to the limit of approximately 16 c./s., and the uniform radiation of the sound, as high directional intensities are very undesirable, except perhaps in exceptional circumstances. The problem of amplification and the production of notes at the very low frequencies and high loudness levels normally associated with the pedal stops of pipe organs, is a very real one.

It is now common practice in the design of high-power sound-producing equipment to divide the frequency range into two sections, using separate loud-speakers for the high- and low-frequency ranges, respectively. This has led to the development of multi-cellular speakers for the high frequencies, which have in some measure overcome the difficulties arising from undesirable directional radiation in this range of frequencies. Such loud-speaker systems are at the moment costly and very bulky.

A loud-speaker system which has been specially developed for use in conjunction with electronic organs incorporates an amplifier having a suitably extended frequency response, and high- and low-frequency range loud-speakers of special design.[55] These speakers have stretched aluminium foil diaphragms mounted on circular rings. The diaphragm has a moving-coil drive and at low frequencies operates approximately as a piston in the surrounding baffle. The polar distribution of the sound radiated from this form of loud-speaker is extremely uniform so that there are no undesirable focusing effects. Sound-producing systems of this form are actually incorporated in electronic organs of the design depicted in the next Section.

One problem in connection with sound-production systems which has received considerable thought in the sound-recording and broadcasting fields is that of artificial reverberation.[56] This is of particular interest in relation to electronic organs, as some suitable means of introducing artificial reverberation into the system would help to solve the difficulty of the " dead building " —a problem with which the organ builder is continually faced. Many systems have been proposed for broadcasting and other uses, and have been applied with some measure of success, but as far as the authors are aware none has been evolved which may successfully be incorporated in an electronic organ.

(6) GENERAL ASSEMBLY OF A COMPLETE ELECTRONIC ORGAN

In order to indicate the general form of the component assemblies, and the compactness of a complete electronic organ, photographs of one example incorporating rotary electrostatic generators are given in the following figures. The circuit arrangements, etc., of this instrument have already been described earlier in this paper.

Fig. 26 (see Plate 5) is a view of the complete console the overall dimensions of which, without the pedal board, are 49 in. high, 62 in. wide, and 29 in. deep. The pedal board is detachable for convenience in transport and the loud-speaker cabinets, which also house the power amplifier, the size and number of which will depend on the building in which the organ is to be installed, are separate components. In the photograph the stool has been removed so that the pedal board, toe pistons and swell pedals may be more readily seen.

The layout of the keyboards and controls is in accordance with the standards of the Royal College of Organists, and just above the two manuals of 5-octave compass will be seen the three groups of stop keys associated respectively with the pedal organ, on the extreme left, the great organ, and the swell organ on the right. The tone colours imitated when the various stops in their respective departments are operated, are indicated in the specification for this particular instrument (Table 6). It will be appreciated by reference to Section (5) (D) (*c*) that tone colours of stops of individual instruments can be set to suit the particular requirements by appropriate arrangement of the excitation voltages applied to the busbars by each stop key. Thus, for example, the tone colours of the stops in the instrument shown could be altered to be suited to theatre requirements, instead of as at present the tone colours being imitations of tones mostly associated with those available on church organs. The stops in the specification marked " Mutation " are associated with the two groups of 9 rotary switches which will be seen on the console just below

the bottom of the music rest. When the 8-ft. mutation stop is operated on the great organ, for example, adjustment of the left-hand group of rotary switches enables a tone to be set up at 8-ft. (normal) pitch, having any desired combination of harmonic content available. Each rotary switch has 10 positions, and clockwise movement of the switch adds the particular harmonic which it controls, in steps giving equal loudness increments. The action of the 16-ft. mutation stop is similar, except that the tone in this case will be at 16-ft. pitch, or an octave lower. The two mutation stops operating on the swell manual can be used in a similar manner. Also, any one or all of these mutation stops may be used separately or in combination with other stops of fixed tone colour, and the result will be similar to that obtained when additional stops are drawn on a pipe organ. The thumb pistons (which will be seen under each manual) and the toe pistons (on the sloping panel just above and in front of the pedals) control the appropriate groups of stops. The same principles of design are applied in these accessory controls as are employed in electrically-controlled pipe organs. Actually, in this instrument, the relays operating the stops from these pistons are accessible from the back of the console, and the particular groups of stops which they severally bring into action can be pre-set by the organist to any desired combination in a matter of a few seconds. The balanced swell pedals, controlling the loudness of the stops drawn in the respective departments, are between the two groups of toe pistons.

Fig. 27 (Plate 5) shows the same console with the case removed; the voltage amplifier will be seen on the left-hand side. In Fig. 28 (Plate 6) the keyboards and pedal board have been removed, revealing the note key relays, etc. Fig. 29 (Plate 6) shows the manner in which the stop key relays and the note key relays may be raised in order to give access to the various resistances, for initial adjustment. Fig. 30 (Plate 6) shows the motor and generator assembly, which is normally housed at the back of the note key relays, the motor of which can just be seen on the right-hand side of Figs. 28 and 29.

Although, as will have been gathered from the details given earlier, the circuits are fairly involved, the form of wiring adopted has so simplified the technique that no skilled labour is required to wire the instrument. This also applies to the mechanical assembly, as every component is mass-produced, the majority of the small components being of pressed construction. The wiring technique adopted[57] involves soldering cross-connecting bare wires to appropriate tags on opposite edges of strips of bakelite, these subsequently being fitted into their appropriate positions in frame assemblies in a manner which renders the completing of the circuits a very simple operation.

(7) FUTURE DEVELOPMENTS

Having considered the development of electronic instruments to date, particularly that of electronic organs, it may be interesting to speculate as to future developments. No one will deny, of course, that electronic organs are still in their infancy, as compared with traditional forms of musical instruments. Nevertheless, a stage has now been reached when the designers of electronic organs may be proud of their achievements during the last decade, having in mind the hundreds of years of development which have contributed to the present high standard of excellence of the modern pipe organ. Obviously, immediate attention will be directed towards the perfection of details of design of instruments operating on the principles already referred to in some detail, and it is certain that surprising improvements will follow from the increased range of tone colours and effects which will become possible.

Other principles may be anticipated; for example, the use of a cathode-ray method of wave-form generation has been proposed.[58] The attraction of such a

Table 6

SPECIFICATION OF ELECTRONIC ORGAN INCORPORATING ROTARY ELECTROSTATIC GENERATORS

Compass of manuals—CC to C—61 notes
Compass of pedals—CCC to G—32 notes

Stops of lower manual; or great organ.		*Stops of upper manual; or swell organ.*	
1. Contra salicional	16 ft.	1. Quintaten	16 ft.
2. Diapason	8	2. Geigen	8
3. Gemshorn	8	3. Viola da gamba	8
4. Wald flute	8	4. Gedackt flute	8
5. Dolce	8	5. Salicet	4
6. Principal	4	6. Cor de nuit	4
7. Gemshorn	4	7. Nazard	$2\frac{2}{3}$
8. Open flute	4	8. Flautino	2
9. Twelfth	$2\frac{2}{3}$	9. Contra fagotto	16
10. Fifteenth	2	10. Cornopean	8
11. Tromba	8	11. Oboe	8
12. Clarinet	8	12. Clarion	4
13. MUTATION	16	13. MUTATION	16
14. MUTATION	8	14. MUTATION	8

(i) Swell to great
(ii) Tremulant
(iii) Tremulant

Pedal organ

1. Contra violone	32 ft.
2. Major bass (G)	16
3. Violone (S)	16
4. Sub bass	16
5. Octave (G)	8
6. Bass flute (S)	8
7. Trombone (G)	16

(iv) Great to pedal (v) Swell to pedal

Accessories.

Five double-touch thumb pistons to great and pedal
Five double-touch thumb pistons to swell and pedal
Three toe pistons to pedal
Five toe pistons to swell (duplicating)
One reversible thumb piston for swell to great
Balanced swell pedal operating on great organ
Balanced swell pedal operating on swell organ

Note:—

Pedal stops under control of balanced great and swell pedals are marked (G) and (S), respectively.
The first touch of the thumb pistons operates manual stops only; the second touch operates pedal stops.

method would seem to be the absence of moving parts, although it is difficult to say at this stage whether or not this advantage would be outweighed by the more elaborate nature of the components.

One of the most promising possibilities is the increased scope which will be offered to musicians in modes of expression. Present-day composers are striving to express new ideas, but with traditional musical instruments they are limited to the chromatic scale and the tone colours which are available and which have remained sensibly the same for many years. The electronic organ offers the possibility of new tone colours and effects, and because the tuning is only a matter of mechanical design there should be no difficulty in producing an instrument to play in just intonation, making use of a keyboard of the form suggested by Bosanquet, which was referred to earlier, or the simpler approximation recently proposed by Williamson.[59] In this latter arrangement, notes are selected from two tempered scales having frequencies in the ratio of 119 : 118, and it is proposed to use a normal keyboard provided with selector mechanisms to enable the performer to play at will in equal temperament or in any chosen natural scale. Similarly, the quarter-tone scale presents no particular technical difficulties such as are present in traditional forms of instrument. Theoretically, the scope of the electronic organ is very extensive, but, as has been shown, the practical possibilities are limited at the moment by the engineering problems involved.

From the point of view of compactness, portability, flexibility of control, constancy of tuning, and economy, obviously these instruments have a promising future.

(8) ACKNOWLEDGMENTS

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After the advance copies of the paper had been distributed Mr. Ll. S. Lloyd kindly suggested improved wording for the references on page 518 to musical scales, etc. The modifications have been incorporated for the *Journal*.

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WRITTEN CONTRIBUTIONS TO THE GENERAL DISCUSSION ON THE ABOVE PAPER

Mr. L. E. A. Bourn: It is a pity that the authors do not give more details with regard to the working of the new generator. The circuit given in Fig. 20 and alleged to be "noiseless" is in my opinion no better in this respect than the arrangement shown in Fig. 18, as it is just as essential that good contact be established in either case. Furthermore, this circuit is subject to the disadvantage that two extra components per frequency are required associated with the grid lead.

The latest type of generator invented by one of the authors is stated to show marked superiority over my earlier type; but from the descriptions available I cannot see that this is the case. In my original and later types a single air-gap only is needed, and exposed dielectric is carefully avoided. In this new type, however, not only must there be two air-gaps plus the thickness of the rotor, but the dielectric, however perfect, would most probably give trouble. If the minimum safe gap is, say, 1/64 in. and the rotor 3/16 in., the effective capacitance is reduced to approximately one-sixth with a proportional reduction of signal/noise ratio: also the rotor will acquire charges owing to absorption effects which cannot leak off immediately and would cause greatly increased background noise.

It is probable, however, that the rotor does not behave as a dielectric at all but as a conductor, by virtue of the fact that there is no appreciable current flow. If this be the case, or the mere dusting of graphite or other conductive material would make it so, it would not only result in an increase in efficiency from 1/6 to 1/2 but

would also obviate the evils of exposed dielectric. The disadvantage then is that the rotor is necessarily floating and liable to collect charges as a whole, which is very undesirable. It follows that if the rotor behaves as a conductor the stationary grid electrode acts as a capacitance " brush," and that a p.d. then exists between all three electrodes, which must therefore function electrically exactly as in British Patents Nos. 403444 and 433050 but with reduced efficiency, particularly on the lower frequencies.

Mr. K. E. Downton: With regard to the starting transients, I am not quite clear as to how they are produced; perhaps the authors would give further details.

It would be interesting to know how far normal frequency variations will affect the pitch of the instrument, although thanks to the advent of controlled frequency such variation is usually very small.

The effects of lightning and other voltage kicks must be considerable, but these are happily rare.

With the pipeless organ, where the sound is emitted from what is in effect a point source (a single loud-speaker diaphragm), will not the general effect on the listener be different from that produced by a pipe organ where the sound comes from a larger area, the pipes being of necessity an appreciable distance apart?

The authors refer to the use of mixtures to add brilliancy to the tone of their organ. The usual " three rank mixture " is not mentioned, but perhaps is confined to larger organs.

Each manual has exactly twice the number of " speaking " stops to be found in the pedal organ. Is this a coincidence, or does it simplify coupling and duplicating?

Having regard to the surprisingly compact nature of the layout, it does not appear impossible to design a somewhat less ambitious pipeless organ (with about 25 speaking stops) suitable for use in an ordinary room, provided the cost can be kept low enough. Such an instrument would be a great convenience to organists and pupils.

Lieut.-Commander R. B. Fairthorne: Contrary perhaps to expectation, a demonstration readily convinces both hearer and performer that this equipment is more than an ingenious substitute for the orthodox organ, at any rate so far as the manuals are concerned. The only doubt would seem to be in the successful imitation of heavy pedal effect; and a hint of difficulty in this sphere is given in the paper. A fugal or passacaglian " build-up " lacking in adequately grand effect of the final pedal entry would be depriving itself of musical climax. What is the extent of the limitation?

A valuable feature from the player's point of view is the instantaneous response. With others, I once had the experience of preparing on an old " tracker " for an examination which was unexpectedly held on an instrument—a fine one—with its console situated a considerable distance from the pipes. While the tubular pneumatic action was an innovation to the touch, the sound-lag was rather disturbing, especially in the more rapid passages.

The orthodox organ does not reproduce faithfully when broadcast, being disappointing even to the extent that it is sometimes difficult to distinguish between flue and reed! Does the instrument under discussion offer better possibilities in this field?

Coming to the commercial aspect, it is claimed by the builders that a recurring saving results from the absence of tuning. Will the authors indicate to what extent this saving is offset or balanced by the cost of replacements?

Mr. F. Hope-Jones: I wish that the authors had been a little more precise in the description of their electrostatic generator and in giving reasons for thinking it superior to the well-known " Electrone," which has 800 fine instruments to its credit. It is the only British pipeless organ, and when in the U.S.A. last year I could find no other to hold a candle to it for beauty of tone. The genius of the invention is best expressed by the formula " volts/air," whereas the authors appear to advocate " (volts/2) air + bakelite," without any convincing arguments in favour of an obviously more complex form.

The paper is very comprehensive but I find fault with its perspective. I think the standard types of stator and rotor should have been selected for illustration.

Mr. A. W. Ladner: The construction of most electronic organs is based on the assumption that the sounds made by musical instruments of the wind-organ type can be simulated by a series of discrete harmonic frequencies. In my opinion this assumption is incorrect, and in making this statement I am not of course attacking the mathematical truths of Fourier but am criticizing the basic results of Section 2 (B) of the paper, by suggesting that the measuring equipment available at the moment is inadequate to analyse complex sounds of this type to the degree of accuracy demanded by aural perception.

Have the authors had an opportunity of making a direct comparison of the sound from a musical instrument with the synthesized sound? We carried out such experiments at the Marconi School of Wireless Communication and were at once struck with the surprising fact that in most cases synthesized organ-pipe sounds had only an approximate resemblance to the original, although the sounds from plucked or struck strings could be simulated exactly, provided rough attack and decay circuits were added; this is rather surprising in view of the fact that sounds of the first type are sustained whereas those of the second are transient in character.

It is significant, however, that the second type of sound is made up of a free vibration plus a well-defined decay series, whereas the first type, although sustained and employing a resonating system, derives its energy from what is virtually a pulse type of generator. We suggest, therefore, that the second type of sound, being a free vibration modified by a long decay time, can be simulated by a series of discrete harmonic frequencies, together with the inharmonic content produced from a decay circuit of simple *CR* type. Whereas the first type of sound, although it has no appreciable percentage of decay and attack time (except in very short passages), has, because it is wind-generated, a wave spectrum which still includes a large frequency-spread of low-level inharmonic content as shown in Fig. A, the pulse method of wind generation probably producing amplitude or frequency variations or both. This inharmonic content, however, cannot be adequately added by the provision of attack and decay circuits.

It was observed also that if we ignored the harmonic analysis obtained from the original wind-organ pipe, it was possible to get closer approximation to the original

sound judged purely by aural methods, by a relative increase of the higher harmonics over the analysed values. For instance, in the particular case of a reed (trumpet) pipe, the fundamental needed to be decreased and the higher harmonics increased relatively, the presence of a strong discordant 7th being very important from the point of view of realistic representation.

Another interesting fact was that organ sounds having apparently a very small harmonic content proved very difficult to simulate, such, for instance, as the sound from a bourdon pipe or a clarabella, both of which have a characteristic woolly (or should it be woody?) sound. In the authors' specification of an electronic organ neither the bourdon nor the clarabella pipes appear, although the former is almost universal in wind organs; it would be interesting to learn whether the reason is the difficulties experienced in reproducing their characteristics.

The authors mention the effects of sounds of very low level on the resultant quality, and experiments carried out by us may be of interest in this connection. In our experimental model we have a number of keys which enable us to add any harmonics of a fundamental sound

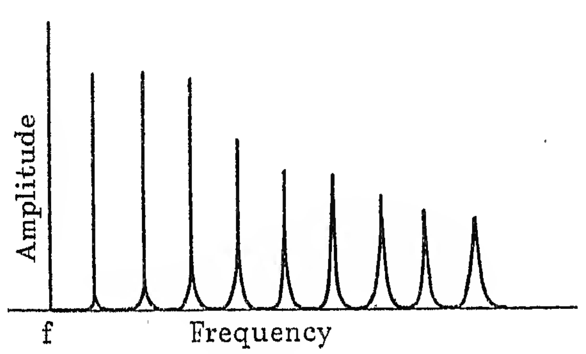

Fig. A

one after the other, or alternatively in groups, at any predetermined level. During these experiments we noticed that with a high-level fundamental (say 40 db. above threshold) when a harmonic at threshold level was switched in, the ear heard that harmonic clearly as a separate note, there being no appreciable masking, and it was only after a lapse of time that the harmonic merged with the fundamental and other harmonics present to form a complex sound. This is of course a physiological property similar to that whereby the eye catches a moving patch of colour even though it is practically identical with the colour of the background. The greater the level of harmonic when switched in, the longer time the ear took to assimilate that harmonic as part of a complex sound. This ability of the ear to pick out a sound-change of very low level appears to us to be extremely important and to explain why a better simulation of complex organ sounds is obtained when the level of the higher harmonics is increased above the correct level as given by the harmonic analyser. As explained previously, we assume the amplitude and possibly the frequency of the higher harmonics of the sounds from the wind pipe are varying to a relatively great degree.

Since our synthesized methods do not employ a variation of the amplitude or frequency, because of this physiological fact mentioned, it would appear reasonable to expect that an increase of amplitude of an unvarying harmonic above the average value as measured by an electrical analyser would give us a better reproduction. This certainly has proved to be the case with most of the organ-pipe sounds we have tried. In the case of the violin, however, because the type of bowing inevitably leads to considerable variations in the number and amplitude of the component frequencies, no amount of faking of the harmonic amplitudes gave a sound even approximately simulating that required.

The general results of experiments carried out here indicate that a number of wind-organ sounds can be simulated approximately by judging the sounds purely from an aural standpoint, ignoring the measured harmonic analysis; but even so the simpler wooden pipes have lost their "woolly" character, the reeds some of their essential edge and the strings their incisive brilliance.

If the object of the makers of electronic organs is to simulate exactly existing wind-organ stops, the addition of harmonic frequencies alone is not the correct way of proceeding. The following alternatives appear open: (*a*) Adoption of a sound track and scanner which gives the particular complex sound required (in this case tracks for every note of the scale will be required). (*b*) Production of an infinite spectrum of sound from which those parts not required can be filtered out. (*c*) Combination of the harmonic series with a means of producing an intermediate non-harmonic frequency content.

There is no question, however, that by the manipulation of the number and amplitude of groups of simple harmonic frequencies a large variety of very pleasant complex sounds can be produced. We therefore suggest that the makers of electronic instruments of this type should not label these sounds with the names of existing wind stops but proclaim new complex tones, which might well be accepted by musical critics as capable of giving composers a means of interpreting not only old melodies but new masterpieces. Having gone so far, is it desirable apart from using a generic classification to adhere to existing "stop" language, many terms of which apply to a variety of wind stops alike only in name and often misleading to an organist strange to the instrument?

Mr. G. J. S. Little: The use of tempered harmonics in electronic organs is a matter of great interest, and I must confess to some disappointment that the authors have not been able to devote more space to it. One would suppose that, in musical instruments of traditional types, harmonics must be exact multiples of the fundamental frequency, as otherwise the physical vibration producing the musical note would have a very complicated wave form which would repeat only after a large number of cycles of the fundamental frequency. It is surprising that complex tones built up from pure tones in which only the octave harmonics are exact give tolerable results. That the musical quality is in fact good I am in no doubt, but it would be interesting to know whether the degree of approximation available in the equal temperament scale is a barrier to the production of certain particularly beautiful musical tones. Does this, to take an example at random, prevent advance from the tone of the organ clarinet stop to the caressing tone that the orchestral artist clarinet player can command? Would it prevent the reproduction of the rich clear tone of the flautist when using the lowest octave—the true fundamental tone—of his instrument? To generate the exact frequencies

required for the "approximate" harmonics might bring the cost of an electronic instrument into the price range of a normal church organ. Perhaps the authors will say whether such an electronic organ has been built.

In Fig. 24, the choice of C, G♯ and F as notes which are shown connected in three successive octaves is suggestive of the omission of the "approximate" harmonics other than the 3rd, 5th, 6th, 10th, . . . etc. This would be in line with the oft-repeated statement that the 7th harmonic is discordant and undesirable. There is, however, no noticeable suppression of the 7th and other discordant harmonics in the sound spectra of actual musical instruments reproduced in Fig. 1. In any case, the equal temperament approximation to the 7th harmonic at least is less dissonant than the true harmonic. What are the 16 harmonics actually used in building up complex tones in the organ described?

As to the arrangements to control the resources of the organ, if the electronic organ is to compete musically with the pipe organ it is undoubtedly necessary to provide the couplers included in the specification and to arrange that the tone-colours controlled by stops can be "added." It is unfortunate if this cannot be done without considerable expense on organs using magnetic generators of the type illustrated in Fig. 23.

The authors quote the description of the organ as the "king of instruments." In volume of sound, yes, but its command of distinctive and separate tone-colours does not compensate for the performer's inability to influence the intensity of individual notes at will by variation in the force with which the keys are struck. By arranging that intensity of sound shall be controllable as in a piano the electric organ would gain an immediate and considerable advantage over the pipe organ. I venture to suggest that the musical connoisseur would willingly sacrifice a good deal of variation in tone colour for the sake of this advantage. A further refinement which I feel would be much prized would be to combine the percussive attack of the piano with sustaining power. It would seem that this could be done by the disconnection of resistance in the decay circuit at a predetermined time after the depression of the key. In an organ responsive to touch it might not be advisable to have the same arrangement for the pedals, but the pedals would be of assistance in contrapuntal music even if only to sustain a note which had been played on the keyboard. The electric organ, with its wide command of tone-colours, needs to be brought to life by the gift of "touch." If, in addition, controlled percussive attack and sustaining power (with piano and harpsichord tone) could be provided, the instrument would merit description as the ideal chamber organ.

Mr. E. B. Mulholland (India): Mention is made of the use of separate loud-speakers for high and low frequencies. I should like to know whether consideration has been given to the employment of a separate amplifier and loud-speaker for the pedal organ. In the organ described the generators for the 16-ft. and 32-ft. stops could apparently be connected to a separate amplifier, while the upper harmonics of these stops and the 8-ft. stops could be dealt with by the main amplifier.

Although 16 harmonics are available in the instrument described, the mutation stops only allow control of 9 harmonics. What is the reason for this, and what harmonics are controlled by the 9 rotary switches? It would be interesting to know whether 7th and 14th harmonics are used, and, if so, whether it has been found possible to use tempered harmonics for these ratios.

A description of an electronic-organ installation of the type shown in Fig. 23 may be of interest, as the arrangement of stops and technique of playing are somewhat different from those relating either to the organ described in the paper or to any pipe organ. This particular installation replaced a large pipe organ in a cathedral church in India, and has been in operation for a little over a year.

The organ has two manuals, and pedals of the usual compass. Each manual is provided at the left-hand end with 12 push buttons resembling typewriter keys. The first is a cancel button, the next 9 are arranged to give preset combinations of harmonics, and the remaining 2 bring into action harmonic-mixing switches, of which there are 2 sets for each manual, arranged above the upper manual. Each button on being pushed releases the others and remains depressed (except the cancel button, which springs up). On the lower (great) manual the 9 preset buttons are arranged to represent successive additions of stops of a pipe organ, up to "full great"; the upper (swell) manual has a few buttons working in this manner, but the majority represent solo stops. There is no swell-to-great coupler. Control of the pedal organ is by 4 toe-pistons, each of which releases the others; one gives a preset 16-ft. and 8-ft. mixture, one connects to harmonic-mixing switches, and the other two are great-to-pedal and swell-to-pedal couplers. The position of these pistons is indicated by illuminated stencils above the manuals. It will be noted, therefore, that when couplers are being used only the stops drawn on the manual which is coupled can be played on the pedals. This results in a very weak bass. Two balanced crescendo pedals are provided, one for each manual; the great crescendo pedal controls the pedal organ except when the swell-to-pedal coupler is in action.

The harmonic-mixing switches for the manuals take the form of sets of 9 draw-slides having 8 positions each. The first 2 give the sub-octave and a 5th above the sub-octave, while the remainder give the fundamental and harmonics up to the 8th, omitting the 7th. The 8th harmonic is, however, inoperative in the upper half of the top octave of keys. The mixing switches for the pedal organ give sub-octave and fundamental only (i.e. 16-ft. and 8-ft.).

Eight loud-speakers are employed, and are arranged four in each of two cabinets, one of which houses the amplifier. The cabinets are each about 4 ft. square by 3 ft. deep—not sufficient to reproduce the lowest note, about 32 c./s. On playing the instrument it was noticed that the 16-ft. range of the pedal organ was much attenuated below the lowest G (about 50 c./s.).

When the organ was first installed the loud-speakers were placed in the main body of the cathedral, and the attack was much too harsh, the notes sounding like the keying of morse. After the pipe organ had been demolished the loud-speakers were transferred to the old swell chamber, a small brick room having an opening about 6 ft. wide by 10 ft. high. The speakers were mounted sideways-on to the opening, and directed slightly upwards

and sideways so as to avoid standing waves. Only reverberant sound therefore reaches the building. This results in " woolliness " of tone and a noticeable delay in building up volume. At large volume it is impossible when singing to distinguish one chord from the next at the far end of the cathedral, and the absence of a strong bass accentuates this.

As regards the playing of the instrument, the arrangement of the push buttons is awkward as it is very difficult, and sometimes impossible, to change the registration without loss of time. The push buttons are in effect combination pistons, and it would have been much better to have placed them below or above the manuals they control, as is the usual practice with pipe organs.

There appears to be a considerable field for electronic organs in India. The pipe organ, embodying in its construction a large amount of wood and leather, is unsuited to the climate in many parts of the country and is a constant source of trouble. It should be remembered, however, that except in the few large cities there are no facilities for maintenance of an electronic organ, and even a simple fault such as a burnt-out valve would put the instrument out of action until the next periodical visit of the maintainer. With pipe organs it is usual to engage the services of a tuner who tours the country, visiting any one place about every 6 months. If a fault develops, it cannot as a rule be rectified until his next visit. However, a fault on a pipe organ usually involves only one stop or one manual, and does not result in complete breakdown. It would thus be an advantage if an electronic organ could be arranged with the loud-speakers, amplifiers, and as much equipment as possible duplicated, using separate channels for each manual, so that the more likely faults would not put the instrument entirely out of action.

Mr. L. L. Preston: The characteristic referred to on page 521, col. 1, often appears in organ flutes, and is not peculiar to " lieblich gedackt " pipes. The effect I have in mind is a percussive one due to over-blowing.

At the bottom of page 522 it might be added that to play on three manuals simultaneously or on three manual tone-colours with the aid of second touch on one manual, presents little difficulty to good organists, and if electronic organs are to become acceptable to such their resources will have to be increased.

The authors' remarks on the effect of small quantities of harmonics in sound waves and the difficulties of imitating starting and stopping transients of pipes indicate, when the results achieved in practice are taken into account, that while it may be theoretically possible to produce an imitation of a £5 000 organ which would deceive most organists, it would cost an enormous amount of money to do so; and up to the present most of the builders of electronic organs have only advocated their use in place of small pipe organs, the resources of which are very limited, or as a means of extending the total resources of larger ones.

For my part, I find the sounds produced by present electronic organs lifeless, and even on an acoustically dead instrument like the B.B.C. theatre organ the electrically produced sounds can at once be detected whether they are used with the artificial echo control or not.

If electronic-organ designers could produce tremulants with variable depth of modulation as well as variable frequency, they would be meeting a long-felt need.

Messrs. G. T. Winch and A. M. Midgley (*in reply*): We are unable to agree with Mr. Bourn that the circuit in Fig. 18 is as noiseless as that in Fig. 20. In the former circuit, due to Mr. Bourn, in which the valve cathode is earthed and the brush connection is direct to the grid, in the event of poor brush contact developing, any resultant small variation in contact resistance, or possibly contact e.m.f., will modulate the signal voltage across the comparatively high-impedance grid circuit of the valve, and therefore be amplified. In the circuit in Fig. 20, any such variations in contact resistance or contact e.m.f., should they arise, will occur in the excitation circuit, where the resultant effect is clearly very much less critical.

It is true that in the form of generator shown in Fig. 21, and having a bakelite rotor, the air gap is of necessity double any minimum safe value required in generators of the form of Figs. 18 and 20. However, Mr. Bourn's assumption that the bakelite rotor is behaving as a conductor is incorrect. His prediction that this type of generator will suffer from serious background noise due to stray charges on the bakelite rotor is not borne out in practice. On the contrary, the background noise is very small in this type of generator, owing to the absence of moving contacts. This form of construction, with its comparatively large clearances and absence of moving contacts, is shown in practice to be easy to assemble and maintain, and there are no indications of insufficient signal strength.

We would refer Mr. Downton to Section 5(D)(c), and the regulating resistance and network in Section A of Fig. 24. Each note-key circuit has one such resistance-capacitance network, the values in which control the rate of charge and discharge of the generator stators C or D in Fig. 21. This, in turn, controls the envelope of the wave form of the note produced, and enables characteristic starting and stopping transient conditions to be imitated in some measure, as explained in Section 5(A)(d).

The accuracy to which the frequency of the grid system is maintained constant exceeds that necessary to obtain the accuracy of pitch required in musical instruments, and the only difficulties which arise are those which may occur owing to hunting of the synchronously-driven motor, or inaccurate gearing arrangements in the drive to the generator wheels. The methods of eliminating these latter effects are dealt with in Section 5(A)(b).

The effects of lightning and voltage surges should not be troublesome in an electronic organ in which the generators and associated components of the pre-amplifier are adequately screened.

The point raised concerning the difference between the effect of listening to the sound from a pipe organ, coming as it does from a large area, compared with that from a loud-speaker, is interesting, and is touched on in Section 5(E). It would probably be true to say that the polar distributions of sound from the majority of loud-speakers in general use show a pronounced focusing effect at the higher frequencies. This results in the sound being very directional, compared with the

much more uniform distribution from a pipe organ. However, in the paper we have stressed that the special design of loud-speaker used with the electronic organ (Fig. 26) has a polar distribution of sound which is very uniform at all frequencies throughout the range. This characteristic, coupled with the fact that, except in very small installations, more than one loud-speaker unit is employed, minimizes the objectionable point-source effect to which Mr. Downton refers.

It is true that a 3-rank mixture stop is not included in the particular organ specification given in Table 6. Such a stop could be imitated in the same manner as those already included, although, of course, it would involve note-key and stop-key relays equivalent in number to those required for three normal stops. There is, however, no fundamental difficulty in this, and in a larger instrument mixture stops could be included.

The fact that each manual has twice the number of speaking stops to be found on the pedal organ is a coincidence in the design. It is doubtful whether a two-manual and pedal electronic organ of similar general design but in which the number of speaking stops had been reduced from 35 to 25 could be made at a very much reduced cost, as all the most expensive components would still be needed. However, considerable simplification would result if only a single-manual and pedal instrument were required. The marketing of such an instrument had been contemplated, but had to be abandoned owing to the war.

Lieut.-Commander Fairthorne doubts the adequacy of the pedal stops of an electronic organ, and notes that we have referred to the difficult problems which arise in this connection. The degree of success achieved in this department of the instrument is at present limited in the case of larger installations by the number and size of power amplifier and loud-speaker units which it is commercially practicable to use, and consistent with an expenditure not out of proportion to that of the rest of the instrument. The pedal organ is adequate in the case of an instrument installed in a small hall, as it will be noted by reference to Figs. 21 (A) and (C) that the generator for the bottom two octaves is constructed with large scanning members in order to provide adequate signal strength at these low frequencies.

It is probably true that the limitations in the quality of broadcast reception of pipe-organ music is, in general, restricted more by the receiving than by the transmitting apparatus. Where this is the case, it follows that the electronic organ when broadcast would not be expected to produce better results than are achieved with a pipe organ. Commander Fairthorne will probably remember that the Coupleux valve organ, referred to in Section 5(B)(a) and installed in the Poste Parisien Broadcasting Station, was connected direct to the input side of the transmitter, for broadcasting. This dispensed with the necessity for the usual sound studio, and the microphone method of feeding into the transmitter.

Our experience to date is that, in the type of electronic organ described, there are no recurring repair or replacement expenses comparable with those incurred in the regular quarterly (or in some cases more frequent) tuning of pipe organs. It will, of course, be necessary to replace the valves of the amplifier when they fail, but, as their average life runs into thousands of hours, replacement will only be necessary after long periods of service.

We would draw Mr. Hope-Jones's attention to our intentional omission of trade names of the electronic organs described in the paper, which includes the instrument to which he refers. In all cases only the inventors' names have been mentioned, and the *technical* features of the designs appraised. We understand from Messrs. John Compton that the *total* number of their instruments of the electronic type, including those which form a component of a pipe organ, is of the order of one-tenth the number quoted by Mr. Hope-Jones. The point raised concerning the efficiency of the respective generators is already dealt with in our reply to Mr. Bourn.

Mr. Ladner's remarks concerning the discrepancies which he has found when attempting to synthesize tones from the components of the published analysis of harmonic content confirm our experience. This point was not mentioned in the paper because investigations in this field were in hand at the time the paper was presented, but were far from complete. Unfortunately this work had to be suspended at the outbreak of war. The various tone colours were therefore set up by modifying the theoretically required harmonic content until the best imitation was obtained, as judged by ear.

The remarks concerning Fig. A are very interesting and support our references in Section 2(B) to the important part played by inharmonic components in contributing to the character of certain tone colours. Mr. Ladner is doubtless familiar with the methods of synthesizing speech which have recently been demonstrated in America and described in the February issue of *Electronics*. Here the inharmonic noise components required in addition to the harmonic components for producing true imitation of speech, are supplied by amplifying valve noise and suitably mixing it with the harmonic components.

Concerning the suggestion that the mixing of harmonics alone is insufficient to enable the exact tone qualities of wind-organ stops to be obtained, we would make the following comments: Mr. Ladner will find that the alternative method (*a*) which he proposes, involving the scanning of a complex wave form, is dealt with in Section 5(B)(c) (i) of the paper. His proposed method (*b*) is similar in principle to that used in the imitation of the human voice, referred to in the preceding paragraph; and to some extent his method (*c*) is utilized in instruments of the form referred to at the end of Section 5(B)(a) of the paper. As there stressed, electronic forms of organ are still in the comparatively early stages of their development, and it would seem probable that in due course instruments will be developed combining the features of particular merit of each of the many systems which, up to now, have been developed separately.

The omission from the electronic organ specification in Table 6, of bourdon and clarabella stops, was in fact a coincidence, as this specification was prepared before

the first experimental instrument was constructed. However, experiments since made confirm the difficulty of imitating correctly the clarabella tone.

We have, in Section 5(A)(h), advanced reasons for the retention of the normal form of pipe-organ console, namely in order not to embarrass contemporary organists. For the same reason it would appear unwise to give entirely new names to electronic organ stops, at least for the present. The special tone colours available on electronic organs could be given new names and incorporated as additional stops, or, as in the instrument of Fig. 26, derived from suitable settings of the "mutation" stops, in which the harmonic content is adjustable from the console.

Mr. Little may prove to be right in his suggestion that in order to reproduce the more delicate tone qualities, true, as apart from "tempered," harmonics may be found necessary. As always, the difficulty in the launching of a new form of product on the market is to decide at what stage this should be attempted. There is still a great deal to be done in furthering the development of the electronic organ, and doubtless all these finer points will be studied and the instruments steadily improved. It has, however, seemed to the builders of electronic organs that the development has already reached a stage when the instruments are of considerable musical interest and, as Mr. Little presumes, further refinements, at least in the earlier stages of development, would inevitably increase the cost of the instruments.

The 16 harmonics used in the instrument of Fig. 26 vary with the particular stops and the position of the notes in the register. In general, they are selections from the first 16 harmonics, shown in Table 1, but in the case of some of the lower notes of certain stops tempered harmonics up to the 24th have been used.

Although in the electromagnetic generator circuit of the type of Fig. 23 it is not possible to obtain the additive effect of stops of different tone colours, as in a pipe organ, as pointed out in Section 5(D)(a) and (c) the effect of adding notes and stops is simulated in the photo-electric and electrostatic type instruments. Also, in the instrument in Fig. 26 the normal manual and pedal coupling effects common to pipe organs are simulated.

The control of attack by means of the touch applied to the keynote, which Mr. Little thinks would be a desirable feature in electronic organs, together with percussive effects, have been tried with varying degrees of success. In Section 5(D)(c) and reference (53) details are given of the methods already used in electronic organs for obtaining percussive effects. Also, a number of methods have already been proposed for controlling the attack and volume by suitable circuit arrangements associated with the note keys so that the organ is sensitive to touch. Actually, the instrument described in Section 5(B)(a), reference (30), is, in some measure, touch-sensitive.

The instrument Mr. Mulholland describes, which is one model of the electromagnetic organ of the type referred to in Figs. 22 and 23, only differs in the particular design of the controlling devices, and is in all other respects similar to that described in the paper.

It is interesting to note Mr. Mulholland's view that the electronic type of organ is likely to fulfil a need in India, as it is less likely to be affected by climatic conditions than is the pipe organ. The point which he mentions concerning the difficulty in outlying districts of obtaining replacement components such as valves, and his suggestion that as many components as possible should be duplicated in order to avoid complete breakdowns, are worthy of note by designers of instruments for this market.

The suggestion that a separate amplifier and loudspeaker should be used for the pedal organ has been considered and would seem to be a desirable feature in large installations. This would, of course, add to the cost, which must be considered.

The harmonics available on the adjustable "mutation" stops of the instrument in Fig. 26 are the first 9 "tempered" harmonics. The addition of further harmonics for use with these "mutation" stops would, in our opinion, have increased the cost of the instrument by an amount out of proportion to the added advantages, in view of the difficulty likely to be experienced by the performer in making optimum use of these extra harmonics.

We note Mr. Preston's remarks concerning the presence in other organ flute stops of starting-transient conditions somewhat similar to that which we referred to in connection with the lieblich gedakt pipes.

There is no fundamental difficulty in fitting electronic organs with double touch and more than two manuals, but of course it implies the inclusion of a larger range of tonal resources, and consequently a larger and more elaborate instrument.

Although in the present stage of development of electronic organs it may appear that they could not be built to compete with very large pipe organs, it must be remembered that electronic forms of organ have only been contemplated since the beginning of this century and that large-scale development only commenced about 10 years ago. In view of the fact that the pipe organ is the product of many centuries of development, a similar degree of finality and perfection is hardly to be expected in what must therefore be considered to be the comparatively early stages of the development of electronic organs.

There should be no difficulty in meeting Mr. Preston's need for a tremulant producing variable depth of modulation as well as variable frequency.

ANALYSIS OF THE EFFECT OF SCATTERING IN RADIO TRANSMISSION

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SUMMARY

It has been known for a long time that signals from strong commercial stations can be received in the skip zone. Early investigations with a short-wave Adcock direction-finder showed that the signals within the skip zone are in general characterized by absence of bearing. The present paper is a complete investigation into the causes of such effects. It was found that they are due to momentary irregularities and small clouds in the E region of the ionosphere. These irregularities produce scattered signals. The investigation, first carried out with the Adcock direction-finder, was later made more definite and accurate by using short impulses from high-power stations. The later investigations entirely confirmed the original deductions.

The effects of such scattering on long-distance transmission, direction-finding, etc., are discussed. The phenomenon is considered to be a major factor in practically all transmissions.

(1) INTRODUCTION

It is well known that the general features of long-distance transmission can be interpreted in terms of a simple ray treatment of an ionosphere consisting of a number of slowly varying horizontally stratified layers. By means of the pulse technique, a detailed explanation of the main phenomena obtained at vertical incidence has been given, including the effect of magneto-ionic double refraction. By using Martyn's equivalence theorem[1] with the modification for a curved earth given by Smith[2] and by Millington,[3] the general results to be expected at oblique incidence can be predicted, and the complex multiple-echo patterns obtained on long-distance transmissions can often be analysed.

It was realized, however, even before the advent of the pulse technique, that there were long-distance transmission phenomena which could not be explained in terms of such a simple ray theory—in particular, the reception of signals from stations within the skip distance, and the occurrence of bearings on short-wave transmitters which have no relation to the true great-circle bearing, especially under certain conditions of light and dark along the great-circle route. Such apparent anomalies have been classed under the general title of scattering, since the signals obtained can be explained by assuming that the waves are scattered from a series of isolated ionic clouds, rather than reflected in a regular manner from an extended layer. In one sense each individual electron in the layer can be regarded as a scattering source; but in a slowly varying stratified layer, when the distance apart of the electrons is very small compared with the wavelength, the net effect is to produce a regular reflection. As distinct from this process, true scattering may be defined as being produced by local concentrations of ions in the form of clouds which are separated by distances comparable or large compared with the wavelength, or by any process in which there is irregular reflection, such as may possibly occur at the earth's surface or even at the surface of the sea.

It is obviously a difficult matter to draw a clear distinction between regular reflection and scattering, and in practice it is often convenient to include under scattering the partial reflections which are obtained from regions where there is a rapid variation of refractive index, often accompanied by gradients in the horizontal direction. But no theory of the process of long-distance transmission can be complete which does not take into account the effects of scattering; and actually the use of short-wave direction-finding systems, and of aerial systems such as the "M.U.S.A."† for mitigating selective fading and the interference and distortion arising from multiple-echo reception on the true great-circle path, may be seriously limited by such effects.

It was therefore thought necessary, as a preliminary to the analysis of long-distance transmission, that the effects of scattering should be thoroughly known and clearly analysed. In this paper a study is made of results obtained with high-power pulse transmissions, since it was realized that the scattering effects observed on commercial stations cannot ordinarily be obtained with the relatively small power used in most vertical-incidence ionospheric research by the pulse technique. The use of high-power pulses has revealed the scattered echoes which are otherwise below noise level, and the results confirm and amplify the deductions made from the earlier experiments.[4] The question of the physical causes of the inequalities, such as ionic clouds, which have been found to exist, will not be discussed here, but it has been dealt with to some extent elsewhere.[5]

(2) GENERAL DESCRIPTION OF THE EARLY EXPERIMENTS

The main aim of the experiments is to discover the nature and the cause of the signals received in the skip zone, but they also deal with the lateral deviations and the angular spread of signals received beyond the skip zone.

The earliest experimental evidence of scattering was obtained from observations made at Chelmsford in 1927 when the short-wave beam stations were first opened. The procedure was simply to take bearings on an Adcock aerial system, using ordinary traffic signals, and to observe the minima aurally. The results were described

* Marconi's Wireless Telegraph Company, Ltd.

† Multiple-unit steerable antenna. See H. T. FRIIS and C. B. FELDMAN: *Proceedings of the Institute of Radio Engineers*, 1937, **25**, p. 841.

in the *Journal*,[4] and they showed that signals from a high-power transmitter working on a frequency well above the critical frequency at vertical incidence could be received at all distances up to the extreme ranges of long-distance transmissions. Such signals showed no signs of direction within a certain limited zone, unless the transmitting aerial was a directive beam, in which case the apparent direction of travel of the waves received was approximately the opposite to that in which the beam of rays was projected.

These results led to the theory that the waves sent out were scattered back from some point or points on the path of the primary beam. In support of this idea it was shown, from the known centre-lines of the projected beams and the apparent directions of reception of the scattered signals at Chelmsford, that the observations constitute an approximate triangulation of the positions of the scattering sources, which gives a consistent picture suggesting that the sources are situated at and beyond the edge of the skip zone. Owing to the limitations imposed by the use of an aural method, this interpretation was not entirely conclusive, but it was confirmed later, towards the end of 1933, by repeating the experiments and observing on a cathode-ray-tube indicator.

For this purpose the output stage of the receiver used in the previous experiments was converted to a d.c. amplifier so that unmodulated C.W. signals could be observed. Advantage was then taken of the fact that commercial stations often send between traffic a series of regularly spaced dots, which could be observed on a linear time-base synchronized by hand. Fig. 1 (see Plate 1, facing page 556) shows a set of photographs taken when the speed was 25 dots per second. The transmitter was situated at Ongar, Essex, and had a beam directed on Salisbury, in South Africa. The frequency was 19·5 Mc./s., and so was well above the critical frequency at vertical incidence. The Adcock direction-finding receiver was situated only a few kilometres to the east, at Chelmsford, so that a strong ground signal was obtained in a direction nearly at right angles to the direction of the beam.

Fig. 1(*a*) shows the ground signal with the scattered signal overlapping it, Fig. 1(*b*) shows that the scattered signal could be suppressed at a particular setting of the goniometer and that the ground signal was then at a maximum, and similarly in Fig. 1(*c*) the scattered signal was at a maximum when the ground signal was suppressed. The position of the goniometer when the scattered signal was suppressed indicated an almost southerly bearing, showing that the signals were being scattered back from regions which were "illuminated" by the beam, and, from the time-delay of the beginning of the scattered dot relative to the beginning of the ground-signal dot, it could be shown that these scattering regions were beyond the skip zone.

These experiments thus amply confirmed the general conclusions already arrived at, but it was obvious that a much more detailed analysis of the scattering could be made by using narrow pulses instead of the morse dots, which with their rapid start and sharp cut-off were in effect very broad pulses. In particular, it was desired to examine the nature of a phenomenon first observed towards the end of 1933, in which short bursts of scattered signal were noticed which almost entirely overlapped the ground dot, and which therefore corresponded to very small time-delays and to apparent distances as little as 100 km.

(3) HIGH-POWER PULSE EXPERIMENTS

The method adopted for keying high-power transmitters with very narrow pulses, of about 0·1 millisec. duration, synchronized with the 50-cycle a.c. mains, has been described in the *Marconi Review*.[6] The original tests were carried out early in 1935 with a 40-kW transmitter at Ongar which has a series of four spot frequencies, namely 9·275 Mc./s., 11·57 Mc./s., 13·54 Mc./s. and 18·595 Mc./s. (i.e. 32·35 m., 25·93 m., 22·16 m., 16·13 m.), the change from one frequency to another being effected in a few minutes. Later on, another transmitter at Ongar was used which radiated 16 kW on 7·59 Mc./s., and finally a programme on a 16-kW transmitter on 8·005 Mc./s. at Dorchester was added. The aerials used were mainly vertical structures radiating equally all round, and the amplitude of the pulses was practically equal to the C.W. amplitude of the transmitter at full power.

In the case of the Ongar stations the a.c. mains supply was locked by the common system of the Central Electricity Board to the mains supply at Chelmsford where the receivers were situated, so that automatic synchronization of the transmitter pulses with the receiver time-base was obtained to produce a stationary picture on the cathode-ray tube. In the case of the Dorchester transmitter, where there was no C.E.B. supply available, the pulse generator was keyed by an a.c. voltage, suitably amplified, which was sent by telephone line from Somerton, where the C.E.B. supply is usually locked to the section of the C.E.B. system supplying Ongar and Chelmsford.

The reception took place mainly at Broomfield, about 1·6 km. north of Chelmsford, Essex. The distance from Ongar was 19·2 km. and from Dorchester 232 km. The signals could be received on two different receivers, each fitted with the usual cathode-ray-tube equipment for either photographic or visual recording. These receivers were housed in huts about 50 m. apart. One was associated with a short-wave Adcock-aerial direction-finder,[4] and for the purposes of these experiments it is only necessary to know that this aerial and its associated circuits gave a correct indication of direction within about ± 2° on any single reflected ray whose angle of incidence was greater than 25–30°.

In the other hut the receiver could be coupled to three types of aerial. The first was a simple inverted-L type suitable for waves in the range of frequency used, and the second was a crossed-frame aerial which could be used to determine the polarization of the downcoming rays, or to separate the ordinary and extraordinary components.[7] The third was a pair of spaced frame-aerials which could be coupled into the input of the receiver.[8] It consists essentially of two aperiodic frame aerials 20 m. apart, fed by twin-wire shielded cables to a central unit where the relative phase between the two inputs can be measured. The unit is first adjusted by means of an amplitude control so that two signals in phase will give a zero resultant signal on the grid of the first

stage of the receiver. The phase between the incoming signals in any actual case is then measured by introducing a known phase to oppose it and restore the balance in conjunction with any necessary amplitude adjustment.

Tentative experiments were made in February, 1935. These were followed by another series in February and early March, 1936, and finally by a regular weekly programme from 0930 to 1130 G.M.T. starting on the 27th March, 1936. Some weekly night programmes (from 2200 to 2400 G.M.T.) were also carried out in the summer of 1936. A large amount of material has been obtained which, in general, shows definite and permanent characteristics.

(4) GENERAL RESULTS

At the time when the first high-power pulse tests were made, the critical frequency of the F layer was nearly always less than 8 Mc./s., and in general no F echoes were obtained. Under these conditions, when the working frequency f was greater than the critical frequency f_0, no echoes would be obtained with the ordinary low-power pulse technique, but the high-power tests immediately revealed the type of echo pattern which had already been predicted from the earlier experiments on commercial morse signals. The echo patterns on all frequencies were alike in general characteristics, and Fig. 2 (see Plate 1), shows a set of photographic records taken on the morning of the 20th February, 1936, on each of the four spot frequencies of the 40-kW Ongar transmitter. The horizontal axis represents a linear time-scale, the whole base being 20 millisec. The ordinates represent the amplitudes of the impulses received. The great disparity between the amplitudes of the ground wave and of the echoes makes it necessary to limit the ground-wave amplitudes by saturation, so that the apparent amplitudes of the ground wave and the reflected impulses are not a faithful representation of the actual amplitudes.*

In each case the ground signal is followed by a diffuse echo of some milliseconds' spread, quite different from the normal type of echo, which is usually a replica of the ground signal. This scattered echo, as we may call it, can obviously be identified with the type of scattered signal described above in Fig. 1, and the pulse experiments reveal the detailed nature of these echoes. The echo has almost invariably a sharply defined leading edge which remains constant in position, even when the amplification of the receiver is greatly increased. The delay time of this leading edge varies in the daytime from about 7 to 15 millisec. as the frequency is increased, and at night on the highest frequencies it may be as great as 30–40 millisec.

On increasing the amplification of the receiver, the apparent spread of the echo increases, as though the echoes decreased more or less exponentially with increasing time-delay, the more distant echoes disclosed on increasing the amplification finally becoming too weak to be recorded, or else being swamped by receiver and other noises. The structure and spread of the scattered signal can be seen more clearly in Fig. 3 (Plate 1), a record obtained when an impulse transmission from Ongar on a 22-m. beam to New York was received at the Brentwood receiving station on a commercial receiver and beam aerial with a very good signal/noise ratio. It is clear from this Figure that the spread of the scattered echo may be very large, and is only limited by the weakness of the long-delay signals relative to noise. We can also see that the echo is made up of a number of individual impulses each fading independently and at random. In spite of this, the envelope of the scattered signal remains remarkably constant, seldom varying anywhere by more than about 6 db. from the average value in the course of many minutes.

The time-delay of the sharp leading edge derived from Fig. 2 is represented in Fig. 4 as a function of the frequency, by plotting it in terms of the equivalent height that would correspond to a reflection from the ionosphere at vertical incidence with the same time-delay. It will be seen that for the higher frequencies the equivalent heights reach the enormous values of 1 500–2 000 km. But later experiments confirm the earlier direction-finding tests in showing that this is definitely not a

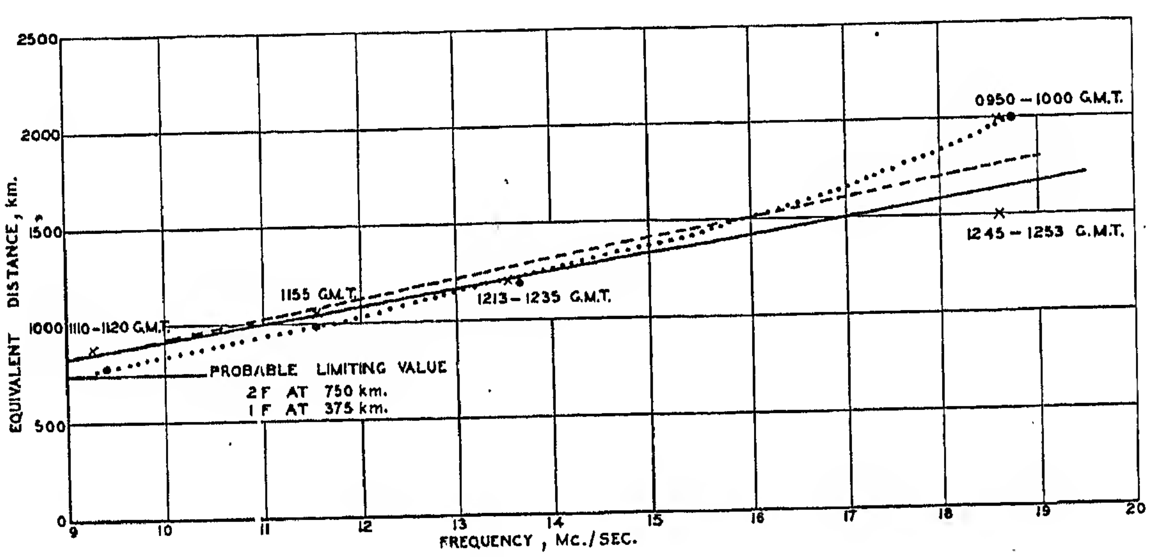


Fig. 4.—Equivalent distances of scattering determined from the leading edges of the scattered groups in Fig. 2, plotted as a function of the frequency, with the skip-distance curve for comparison.

* The ratio of the amplitudes could, however, be easily obtained. An attenuator in the intermediate-frequency amplifier served to control the output level of the signals. To compare the amplitudes of the signals, attenuation was introduced until each signal in turn had been adjusted to the same output level. From the readings of the attenuator the relative strengths of the signals could be determined.

vertical reflection from such heights. In Fig. 4 the curve is also shown of skip distances against frequency, and the similarity to the scattering/distance curve suggests that the two are related. We shall return to a consideration of this relation later on.

In addition to this distant group of scattered signals, Fig. 2 (Plate 1) shows a number of separate echoes of much shorter delay, which, in contrast with the permanence of the distant echoes, are sporadic and short-lived and quite irregular in position. These are obviously the echoes responsible for the short bursts of scattering mentioned above, which had already been observed on the morse transmissions. These echoes, which may be termed "short-distance scattering," have equivalent heights which vary from a lower limit of 60 km. to nearly 500 km. The frequency of occurrence of these echoes varies greatly from time to time and from wavelength to wavelength. The duration of each individual sporadic reflection is of the order of 0·5 sec. but reflections may occasionally last for a much longer time. They are sometimes so frequent that several can be observed simultaneously, but at times intervals of 30 sec. or so may elapse between successive echoes.

The intermittent and random nature of these reflections is shown most clearly in Fig.5(*a*), Plate 2, which represents a continuous trace in time of the equivalent height of the reflecting regions. Fig. 5(*b*) shows more especially the distant group of scattered signals when the leading edge was at an equivalent height of 1 000 km., and Fig. 5(*c*) shows the detailed structure of such a group. Fig. 5(*d*) shows the short-distance scattering at a time when it was very frequent and occurring at the exceptionally low height of 65 km. This record was taken on 7·59 Mc./s. on the 22nd January, 1937, when the density was high enough to give normal reflections from the F layer.

(5) DETAILED STUDY OF SHORT-DISTANCE SCATTERING

We will now, for the moment, put aside the problem of the distant-scattered group and proceed to a more detailed study of the short-distance scattering. Although the delay times of these sporadic echoes are quite irregular, analysis of a large number of observations shows that they have a well-marked height distribution. Fig. 6(*a*) shows the distribution obtained by visual observations, and Fig. 6(*b*) that obtained from photographic records. It will be seen that there is a rather sharply defined minimum height of the order of 100 km. Some echoes as low as 80 or 90 km. have been observed, and a single echo at 50 km. was recorded on the 10th June, 1936, as well as the large number of echoes at 65 km. shown in Fig. 5(*d*), Plate 2, but these are relatively rare. It therefore seems natural to associate them, or at least the ones of lower recorded height, with irregularities in the E layer.

The frequency of occurrence of sporadic echoes of this type seems to be greater on the longer than on the shorter waves used, and on magnetically disturbed days than on quiet days. There is also a marked diurnal variation, of which a typical example is given in Fig. 7, showing the result of a recent 24-hour run using the 9·275-Mc./s. Ongar transmitter. Fig. 8 gives an example of the average duration of these sporadic echoes. The most frequent value is between 0·5 and 1 sec., although some echoes have been observed which have lasted for as long as 2 min. These echoes of relatively long duration appear to belong to a different type from the more usual short sporadic echoes, and it may perhaps be suggested that there is a continuous gradation from them to the abnormal E type of reflection studied by Appleton,[9] Ratcliffe[10] and many other workers.[11]

A large number of these echoes has been examined using the crossed frames of the polarimeter, with which the complete polarization characteristics of a downcoming wave can be determined. Although in a very small percentage of cases the polarization of an individual sporadic echo was definitely right-handed or left-handed, in the vast majority of cases they were unresolved, so that no balance position could be found on the goniometer of the polarimeter. The results suggest that there is a partial reflection at a rather sharply defined surface for which the reflection of both components is nearly the same, and that the differential absorption after reflection must be small.

Perhaps the most definite characteristic in which the short-distance scattered echoes differ from normal reflections is disclosed by experiments with the spaced-frame aerial system. If this is employed to receive the normal E or F echoes from the ionosphere, it is possible, by

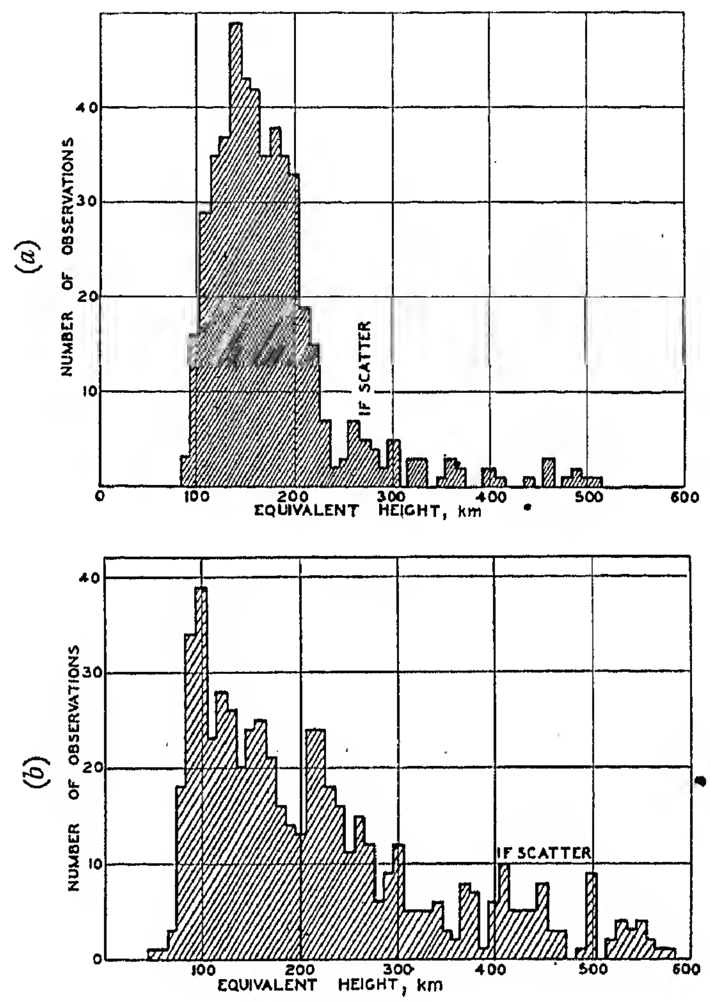


Fig. 6

(*a*) Ongar, 7·59 Mc./s. (39·5 m.); height/frequency distribution of sporadic short-distance scattering obtained by visual observations, August to November, 1936.

(*b*) Ongar, 9·275 Mc./s. (32·35 m.); height/frequency distribution of sporadic short-distance scattering obtained from daytime photographic records, April to August, 1936.

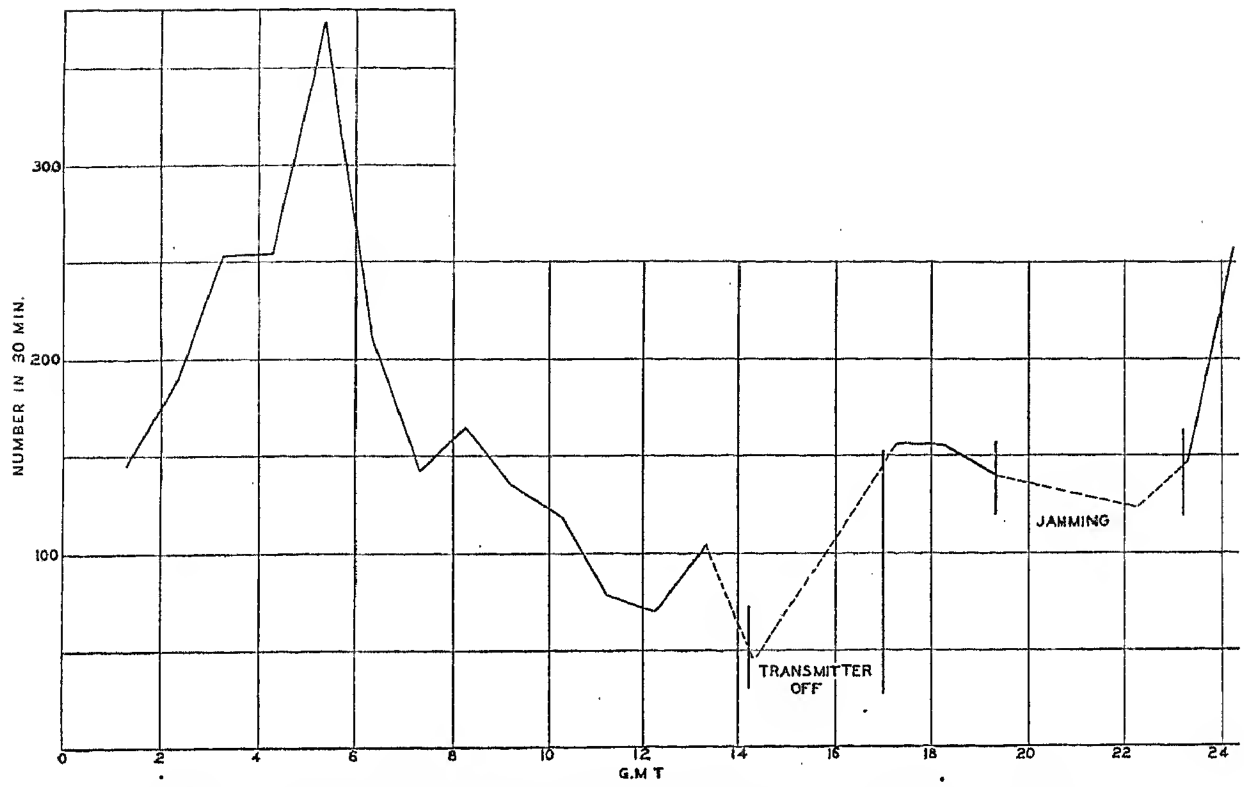


Fig. 7.—Ongar, 7·59 Mc./s. (39·5 m.): short-distance scattering count during 24-hour run, 15th to 16th October, 1938.

adjustment of the relative impedances of the input circuits, to obtain practically a complete balance of signals on the input of the receiver. Such a case is shown in Fig. 9 (Plate 2), in which (*a*) represents an unsuppressed F echo and (*b*) the suppressed one; and in the case of vertical incidence the results show that the signals are of practically the same phase in the two aerials, indicating, of course, that the reflected signal is effectively vertically propagated.

In contrast to the normal E and F reflections, the sporadic short-distance scattering showed no sign of a balance, except on rare occasions, when the aerials were spaced 20 m. apart. When the aerials were spaced 5 m. apart a partial balance was usually obtained. The immediate interpretation of these results is that the signal e.m.f. in one frame is in random phase with respect to that in the other when the two are separated by 20 m., but that a certain degree of correlation exists if the two frames are spaced only 5 m. apart. The detailed behaviour of the spaced-aerial system, and its analogy with the Michelson interferometer for measuring the angular spread of rays and hence the angular diameter of stars, is discussed elsewhere,[12] but it suffices to state that this lack of balance on the spaced frames implies that the reflected signals, instead of consisting of single vertical rays, are fanned out into a cone of rays with angles comparable with 20° or 30° on either side of the vertical. The spaced frames do in fact, at times, actually enable us to locate the positions in space of these ionic clouds by measuring both the elevation and the azimuth of the directions from which the sporadic echoes are received, and accounts of these experiments with diagrams of the cloud locations have already been published.[5,17]

(6) DETAILED DESCRIPTION OF THE DISTANT-SCATTERED GROUP

Before proceeding to a consideration of the detailed significance of the above experimental results, we will return to describe more fully the nature of the distant-scattered group. We have already explained how on the usual interpretation the large delay times would imply reflection at vertical incidence from an ionized region from, say, 1 000 to 2 000 km. above the earth's surface. This possibility has in fact already been suggested by Mimno[13] and by Kirby and Judson,[14] and more recently by Harang.[15] In the present experiments it was observed that when the transmitter had an aerial radiating equally

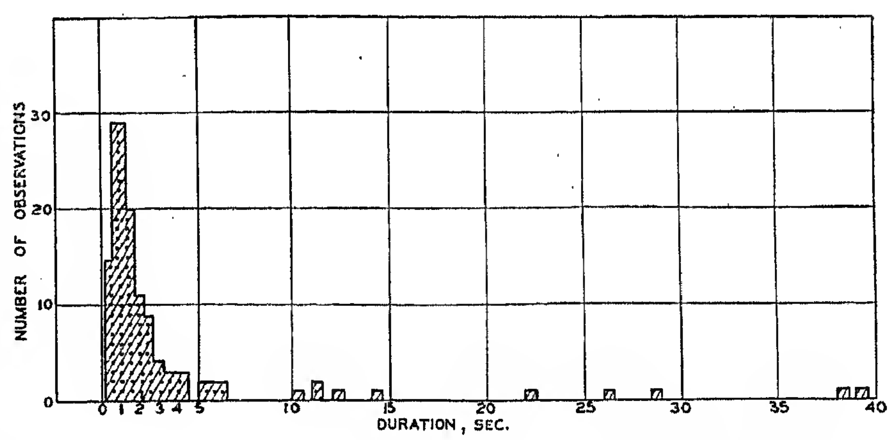


Fig. 8.—Ongar, 7·59 Mc./s. (39·5 m.): frequency/duration graph of the sporadic short-distance scattered echoes, August to November, 1936.

in all directions, the scattered echo gave no signs of a direction when examined on the Adcock direction-finding receiver. This might be because signals are scattered back from all directions from regions in the path of the primary waves, or because the signals are actually vertically reflected. But the latter alternative is ruled out by observations made on the spaced frames, in which no balance could be obtained, proving that the rays were not single vertical rays. To test the former explanation, pulses were transmitted on a directional aerial, and the directions of arrival of the scattered signals observed. The results were identical with those obtained previously

on commercial morse transmissions, in which it was found that the direction of the scattered signal was quite sharply defined, and always opposite to that in which the beam was projected, as is shown in Fig. 10 (see Plate 3). This appears to come to a limit as the frequency is decreased. This limit, as observed in a large number of the above cases where the frequency was less than the critical frequency at normal incidence, is very approximately the 2F

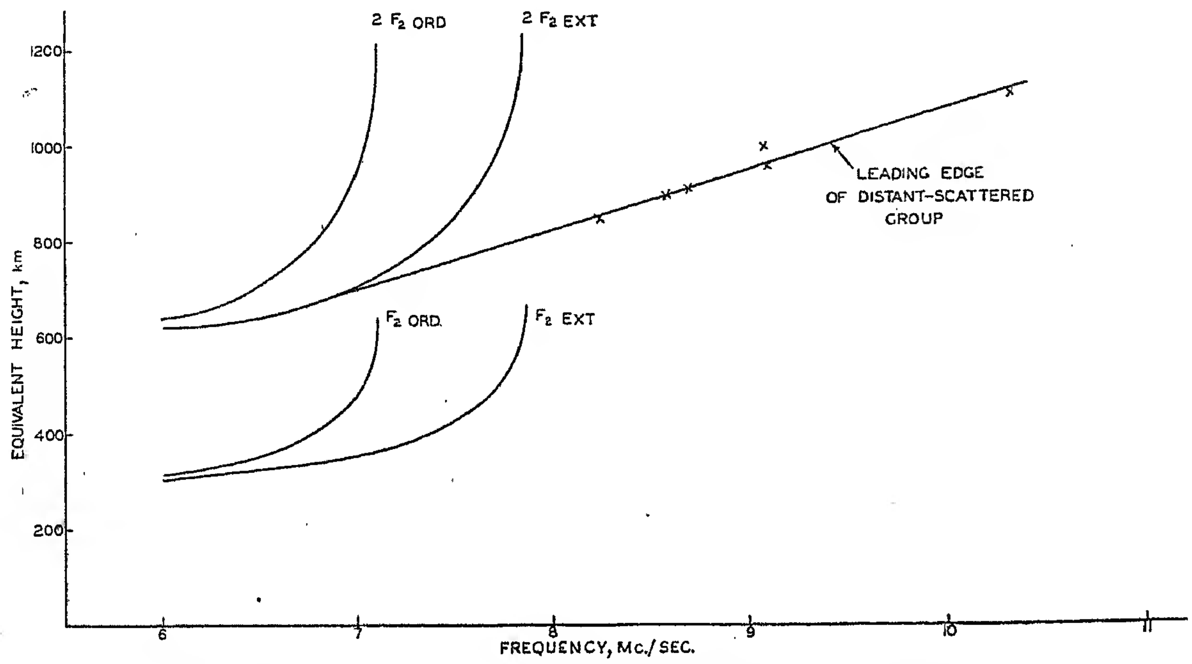


Fig. 13.—Leading edge of distant-scattered group plotted as a function of frequency and compared with the midday *P′f* curve, 10th February, 1937.

confirmed the interpretation that the scattered signals observed when using an omnidirectional aerial were being received more or less equally from every direction in the horizontal plane.

The above characteristics of the distant scattering refer to observations made during the day. At night the scattered echoes are usually much stronger, an effect which can be explained in terms of the reduced attenuation in the E layer; and in contrast with the daytime, even when an omnidirectional aerial is used, the scattered signal is often highly directional and occurs as two or more patches of scattering of different time-delay. When the scattering was of this complex type where there was more than one scattered group, each group had the normal characteristic of a sharply defined leading edge. As a general rule, the first group was scattered from the north, and the second group from the south, while some occasions were recorded when the first group was also from a southerly direction. Fig. 11 (see Plate 3) shows this night scattering in which (*a*) the first and (*b*) the second group has been suppressed.

The conditions obtaining in Fig. 5(*d*), Plate 2, in which the critical frequency was above the working frequency, became more common in the later experiments. F echoes at normal incidence were obtained on some occasions during March and April, 1936, during the morning transmissions on the 9·275-Mc./s. frequency of the Ongar 40-kW transmitter. Typical records are shown in Fig. 12 (Plate 3), and it will be seen that the scattered signal is also present, and is of the same general type as that obtained previously, i.e. a diffuse spread echo with a sharp leading edge. As in the previous cases, a large number of short-distance sporadic scattered echoes was recorded.

The equivalent distance of the leading edge of the scattered group, as shown in Fig. 13, decreases and

equivalent height; that is, the scattering starts at practically the same time as the second-order F echo. Actually, a close study shows that the leading edge of the scattered group is often just slightly before 2F, as can be

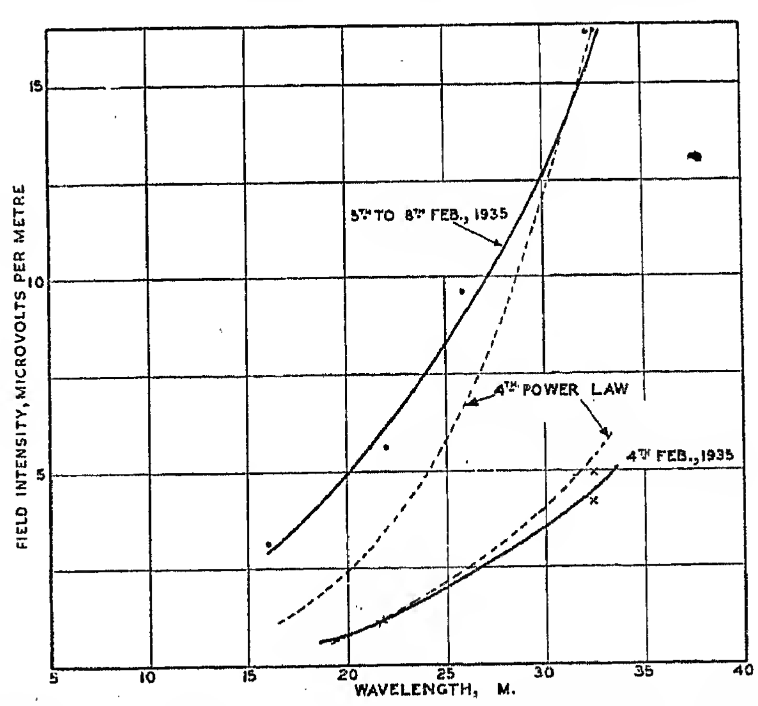


Fig. 14.—Intensities of scattering as a function of wavelength, from observations on Ongar pulse transmissions, with 4th-power law for comparison.

seen from Fig. 12 (Plate 3). This measurement is very significant as regards the estimation of the position of the scattering source.

Many measurements of the intensity of the distant-scattered group have been made. On account of the variable nature of the signals no great accuracy can be claimed, but, by observing the peak of the envelope of the group, an estimate to an accuracy of ± 2 db. can usually

be made. The variation of intensity of the scattered signal with the frequency was determined by a series of tests on the four spot frequencies of the Ongar 40-kW

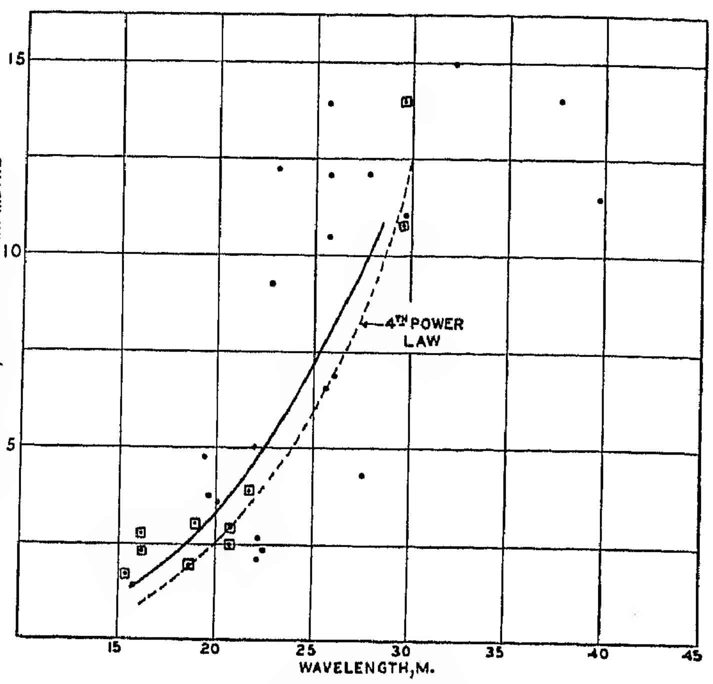
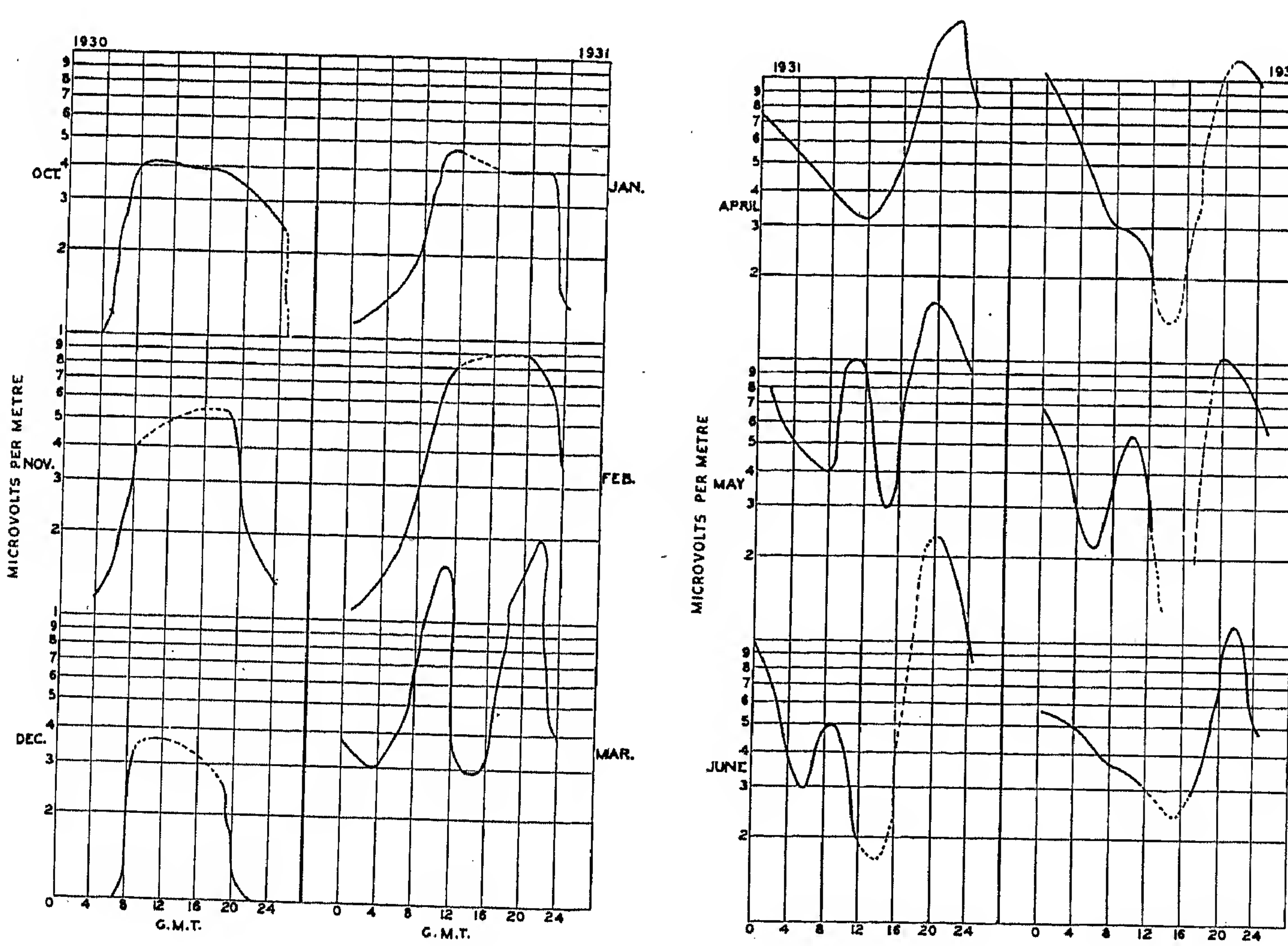


Fig. 15.—Intensities of scattering as a function of wavelength, from observations on commercial stations by reducing the values to a standard 5-kW output, with 4th-power law for comparison.

transmitter. This transmitter radiates nearly the same power on each of the four frequencies, so that the intensities of the scattered signals on the different frequencies could be compared by measuring the ratio of the intensity of the scattering to the direct-ray intensity by means of the intermediate-frequency attenuator in the receiver. The absolute values of the intensities in microvolts per metre were then deduced by measuring the ground-ray intensities on an ordinary short-wave measuring set.

Fig. 14 shows the results (plotted in terms of wavelength) of some tests made during the first week in February, 1935, and Fig. 15 shows the average midday intensity of the scattering for a number of commercial stations between the wavelengths 15 m. and 37 m. (8·1 to 20 Mc./s.) working in the skip zone and reduced to a standard output power of 5 kW. The figures show that for a given radiated power the scattered signals from the shorter-wave stations are much less than from the longer-wave stations, a result which confirms the general experience of 10 years' observations on commercial transmissions.

The intensity of the scattering from any given station has a large diurnal and seasonal variation. This is illustrated in Fig. 16, in which the results of a year's observations for the particular year commencing in October, 1930, of the field intensity of the Bodmin 32·3-m. beam transmitter to New York are shown. This station was at that time always in the skip zone with respect to the receiver at Chelmsford. It will be noted that in the winter the scattered signals were almost wholly confined to the daylight hours, while in the summer the midday skip signals were weak and the night



(a) (b)

Fig. 16.—Intensities of scattering observed at Chelmsford on the 32·3-m. beam transmitter to New York at Bodmin during the year beginning October, 1930.

(a) October, 1930–March, 1931. (b) April, 1931–September, 1931.

signals were strong. Similar results have been obtained for a number of other stations working in the skip zone. These diurnal and seasonal variations are very similar to those which would be obtained for a station of constant

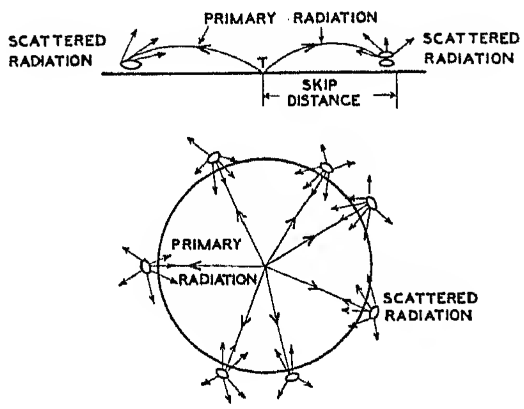


Fig. 17.—Diagrammatic representation of the scattering-back of energy from the edge of the skip zone for a transmitter radiating equally in all directions.

power situated just outside the skip zone, for which the received signal intensity would be controlled by the signals reflected regularly from the ionosphere, since these would predominate over the relatively weak scattered signals.

(7) INTERPRETATION OF THE RESULTS

(a) Relation of Scattering Distance to Skip Distance

The experiments described above deal mainly with the case in which the frequency is above the critical frequency at vertical incidence, so that only those rays which are incident on the ionosphere at an angle greater than a certain critical angle of incidence will be reflected back to earth. The existence of a skip zone round the transmitter, which is predicted by the simple ray theory, is a well-known phenomenon in short-wave wireless transmission, but whereas the theory, even when modified to allow for the effect of the earth's field and the curvature of the earth, implies that no signals should be received within the skip zone apart from the ground ray, we have seen that actually signals are received due to the scattering of the energy back towards the transmitter and the receiver in its neighbourhood. Fig. 17 shows diagrammatically the way in which the energy is scattered back when the transmitter is assumed to be radiating equally in all directions.

The problem of determining the mechanism by which the energy is scattered back is intimately associated with the problem of ascertaining the location of the scattering sources. It has already been pointed out that the delay time of the leading edge of the distant-scattered group is related to the skip distance, and this implies that the scattering sources must be situated somewhere below the F layer, and that the primary radiation reaches them only after reflection from the F layer. The scattered energy reaching the receiver then travels by a similar return path.

In Fig. 18(a) is shown the familiar skip-distance diagram illustrating the path of a ray travelling from the transmitter at T by way of reflection from the F layer at A to a distant point d. When the wave frequency is above the critical frequency, the limiting position of d is at S, the edge of the skip zone. Greater angles of elevation at the transmitter, up to the angle at which the ray escapes, only give rise to the high-angle rays of the pairs of rays received at points beyond S. If for the sake of argument we assume that the energy received at R near to the transmitter is scattered back from irregularities on the ground, such sources must lie beyond S at the edge of

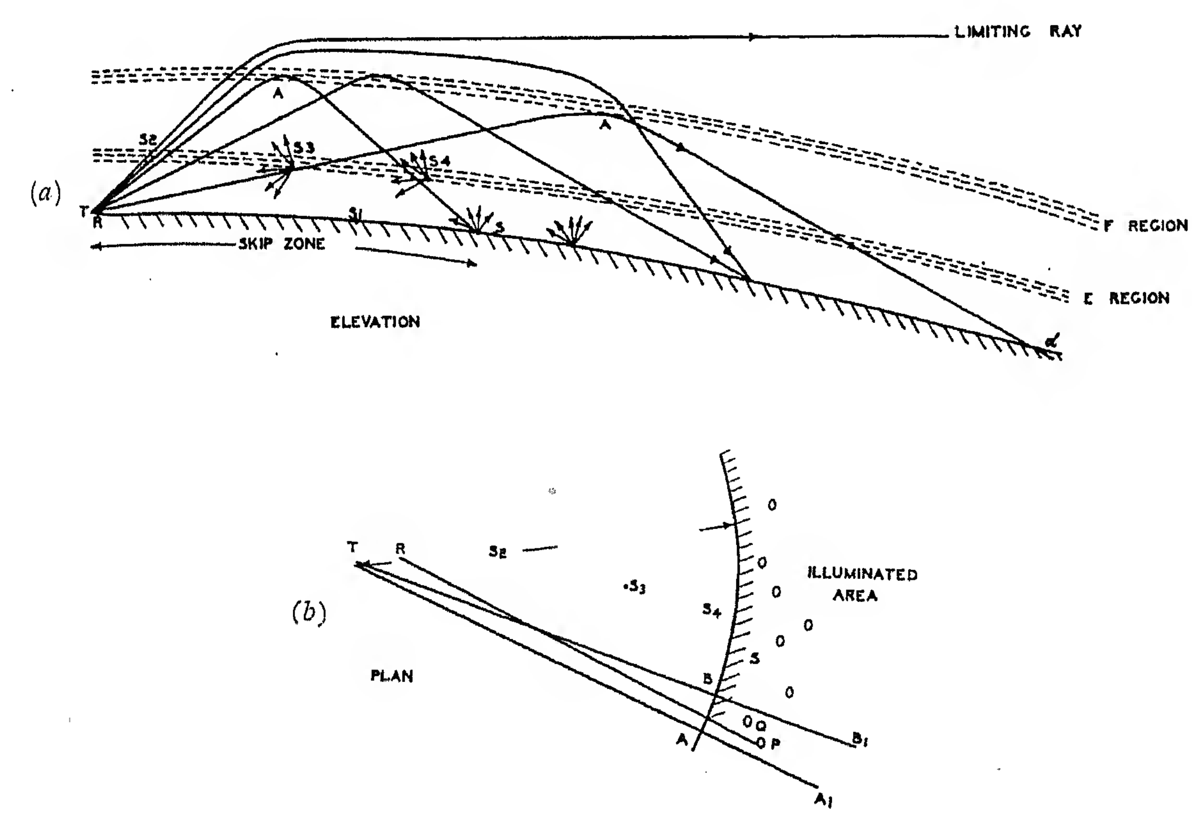


Fig. 18.—Skip diagram to illustrate the path of the primary radiation "illuminating" the scattering sources, and the directional reception of the scattered signal at a point R near a beam transmitter at T.
(a) Elevation. (b) Plan.

the skip zone, since a source such as S_1 within the skip zone is not "illuminated" by the primary radiation.

The delay time of such a scattered signal would increase with the distance of the source beyond S, and this would account for the spread of the scattered echo and the existence of a sharp leading edge corresponding to the minimum time-delay associated with the limiting position S of the scattering sources. When the angle of elevation of the skip ray is small, i.e. when the wave frequency is considerably greater than the critical frequency at vertical incidence, this minimum delay, expressed as an equivalent height, is approximately equal to the skip distance, which explains the general relation between them which has been observed.

As will be seen, the evidence all points to the scattering occurring not at the surface of the ground but from ionic clouds situated somewhere in the ionosphere below the apex of the ray path. It will be observed, however, from Fig. 18(*a*) that the general explanation suggested above of a sharp leading edge associated with the skip distance still holds, the scattering source S_4 shown in the E layer now corresponding to the point S on the ground and giving the leading edge of the scattered group. This picture also gives a very simple explanation of the effects observed with a beam transmitter. This may be better illustrated by considering Fig. 18(*a*) in plan, as shown in Fig. 18(*b*). It is only the small region between AB and A'B' of the zone beyond the skip distance which is "illuminated" by the strong primary radiation reflected from the F layer. Secondary scattered radiation arises at such points as P and Q, and is received at R from the well-defined direction PR which is opposite to the direction of projection of the beam, as observed. This explanation was given by Tremellen in 1927.

As this explanation of the general features of the long-distance scattered group holds whether the scattering takes place from the ground or from sources in the ionosphere below the apex of the primary ray, it will not in itself give any clue as to the height at which the scattering sources are actually situated. An accurate comparison of the skip distance and the delay of the leading edge of the scattered signal would determine this height, but it has been found very difficult to determine the skip distance accurately. More strictly we should compare the delay time of the leading edge not with the skip distance itself, which is the distance TS in Fig. 18(*a*), but with the path time of the ray TAS, i.e. we should compare the path TAS with the somewhat shorter path TAS_4.

Nevertheless, definite methods have been used to compare the skip and scattering distances. The latter are given directly by the observations. The skip-path time can be derived from the normal-incidence $P'f$ curves by the aid of Martyn's theorem,[1] according to which, in cases where the magneto-ionic effects and the curvature of the earth can be neglected, it is possible to derive the oblique-incidence $P'f$ curve for any given distance from the transmitter when the vertical-incidence curve is known. Corresponding to an equivalent height for a given frequency at vertical incidence, there are a simply-related equivalent path and frequency for an oblique transmission to a given distance.

By a simple graphical process it is possible, from any given $P'f$ curve, to determine the distance at which a given frequency which penetrates the ionosphere at vertical incidence becomes critically reflected at oblique incidence. By using the working frequency of the transmitter we can thus find at what distance the primary radiation will be scattered back, or rather we can estimate the skip equivalent path TAS corresponding to the observed scattering distance TAS_4. In Table 1 the results are shown of a series of measurements of the observed scattering distance and of the calculated values deduced from $P'f$ runs taken simultaneously with the observations of the scattering. To show the direct comparison, the calculated values have been adjusted to correspond to scattering occurring at a height of 100 km., i.e. the skip paths TAS_4 have been deduced from values of TAS calculated by Martyn's theorem, by subtracting the distance SS_4.

Table 1

Date	Time (G.M.T.)	Frequency	Observed scattering distance	Calculated scattering distance	Ratio: observed/calculated
		Mc./s.	km.	km.	
3.6.36	1128–1159	9·275	1 300	1 340	0·97
10.6.36	1103–1207	9·275	580	670	0·82
			800		1·19
11.6.36	0012–0035	9·275	1 010	1 030	0·98
17.6.36	1055–1150	9·275	1 000	810	1·23
17–18.6.36	2350–0033	9·275	1 087	914	1·19
24.6.36	1115–1228	9·275	785	768	1·025
25.6.36	0051–0114	14·40	1 751	1 713	1·022
2.7.36	0012–0031	9·275	985	686	1·44
8.7.36	2335–2351	9·275	919	850	1·07
22.7.36	1110–1152	14·40	1 450	1 200	1·21
5.8.36	1103–1151	14·40	1 368	1 360	1·005
				Av.	1·067

The agreement is relatively close, but there is a margin of error because Martyn's theorem is only true where magneto-ionic effects are neglected. The equivalence theorem is likely to be most nearly correct for the ordinary ray, and this has been used throughout the calculations. The results are not accurate enough to use as a criterion for deciding definitely whether the scattering is occurring at a height above the ground, although the agreement suggests that the value of 100 km., assumed in calculating the scatter distances, is of the right order. The results may perhaps be considered in the light of a confirmation of the equivalence theorem for the ordinary ray rather than as a determination of the region of the scattering sources.

The relationship to be expected between the equivalent path of the scattering and the frequency may easily be deduced in terms of a simple ray picture when the earth is considered to be flat and the scattering sources are assumed on the ground. Suppose the leading scattered signal to be reflected from a definite equivalent height h in the F region, and to arrive at the receiver at an angle θ_s to the ground. Then its equivalent distance is $2d$, where $d = h \operatorname{cosec} \theta_s$. Since θ_s is very nearly the same angle

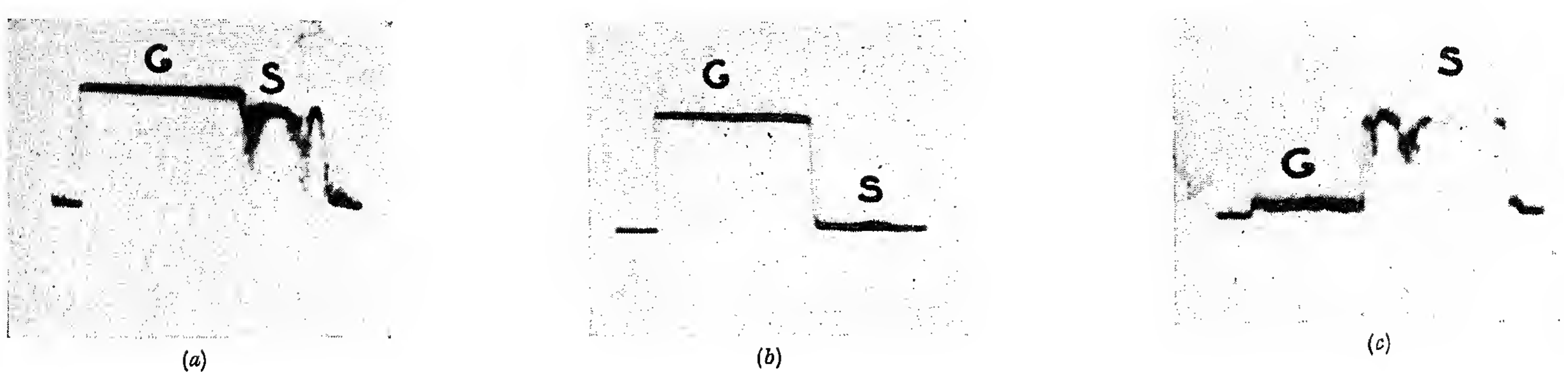


Fig. 1.—Morse dots received on an Adcock direction-finder at Chelmsford from a 19·5-Mc./s. transmitter at Ongar, Essex, with a beam directed on Salisbury, South Africa.

The time scale represents 40 millisec.
(*a*) Ground signal G followed by a scattered signal S. (*b*) Ground signal maximum with scattered signal suppressed.
(*c*) Ground signal suppressed when scattered signal is maximum.

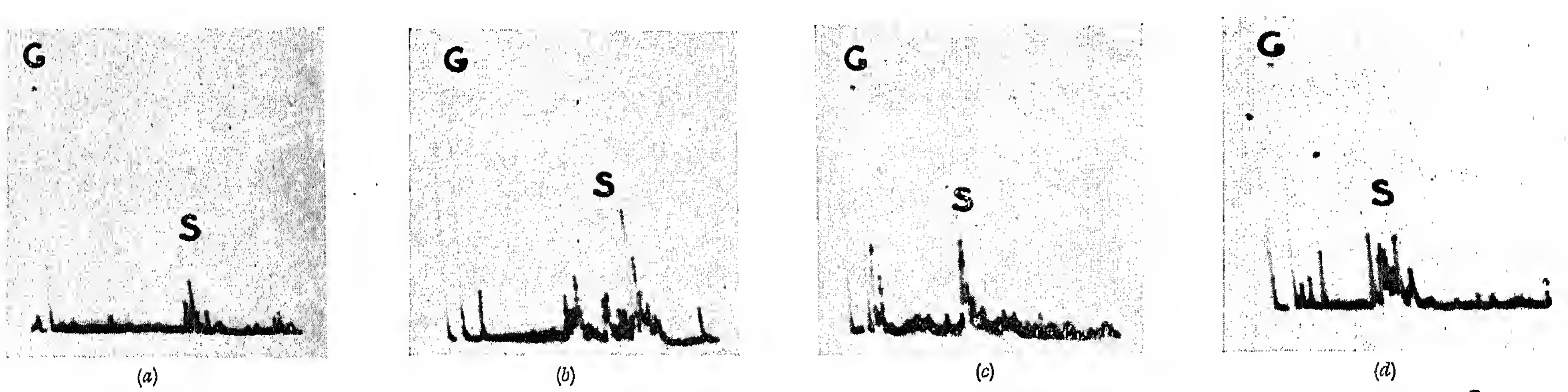


Fig. 2.—Pulse transmissions received on a 20-millisec. time-base at Chelmsford from the 40-kW transmitter at Ongar on the 20th February, 1936. In each picture G is the ground signal and S the distant-scattered group, while examples of the sporadic short-distance scattering following the ground signal can be seen.

(*a*) 1245 G.M.T., 18·595 Mc./s. (16·13 m.). (*b*) 1220 G.M.T., 13·54 Mc./s. (22·16 m.).
(*c*) 1140 G.M.T., 11·57 Mc./s. (25·93 m.). (*d*) 1120 G.M.T., 9·275 Mc./s. (32·35 m.).

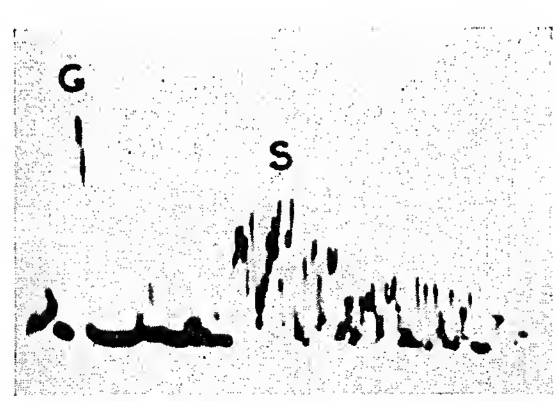


Fig. 3.—Pulse transmission from Ongar on a 22-m. beam to New York received at Brentwood, Essex, on a commercial receiver with a very good signal/noise ratio.

The time-base is 20 millisec.

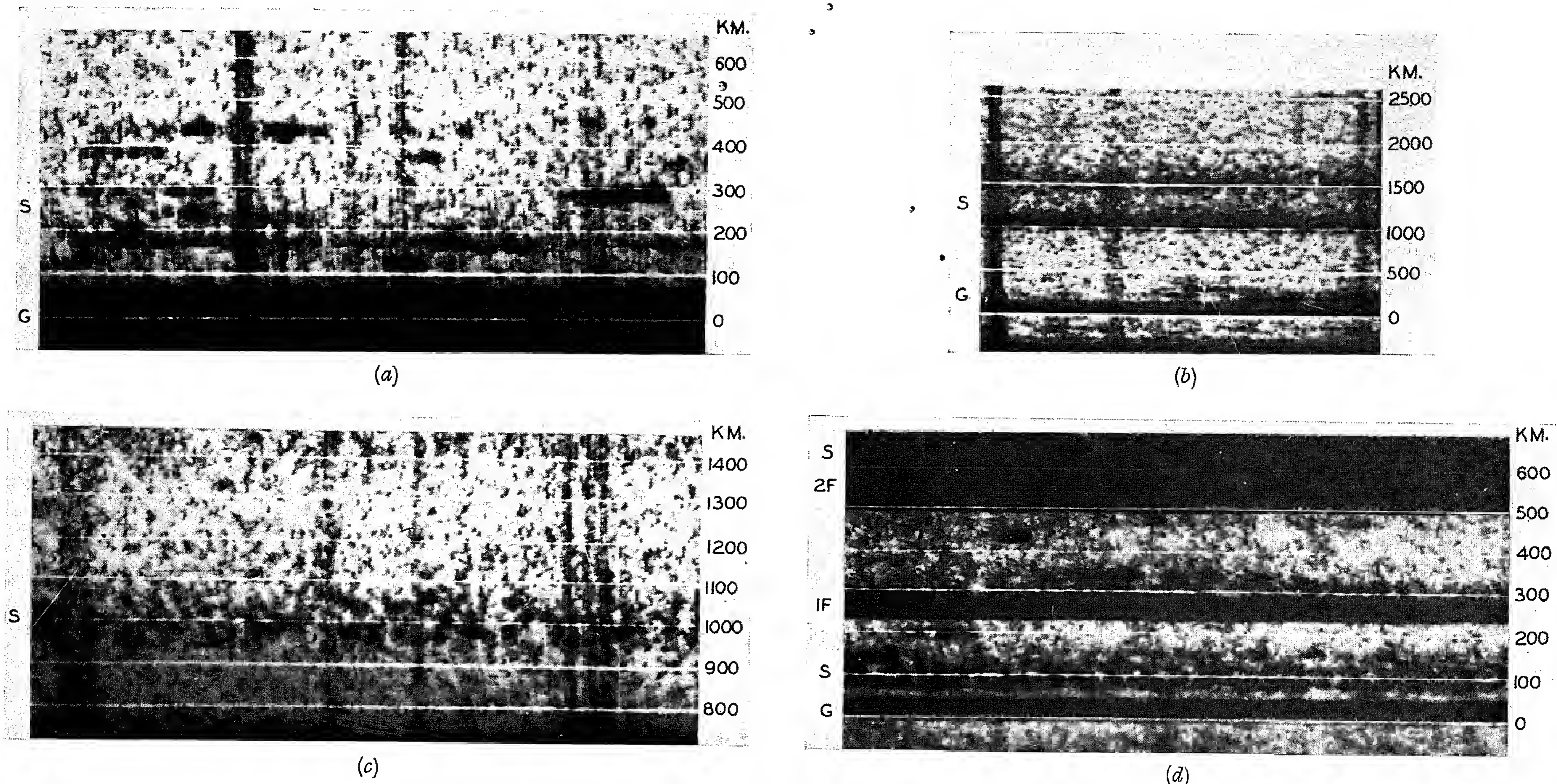


Fig. 5.—*P′t* records showing the detailed structure of scattered echoes.

In each case the overall time is about 20 sec.

(*a*) 9·275 Mc./s., 0015 G.M.T., 19th November, 1936, showing short-distance scattering and no F reflections.
(*b*) 9·275 Mc./s., 0020 G.M.T., 19th November, 1936, showing two groups of distant scattering and no F reflections.
(*c*) 9·275 Mc./s., 0025 G.M.T., 19th November, 1936, showing detailed structure of the distant-scattered group.
(*d*) 7·59 Mc./s., 0930 G.M.T., 22nd January, 1937. Frequency below the critical frequency, F echoes present, short-distance scattering at the abnormally low height of 65 km.

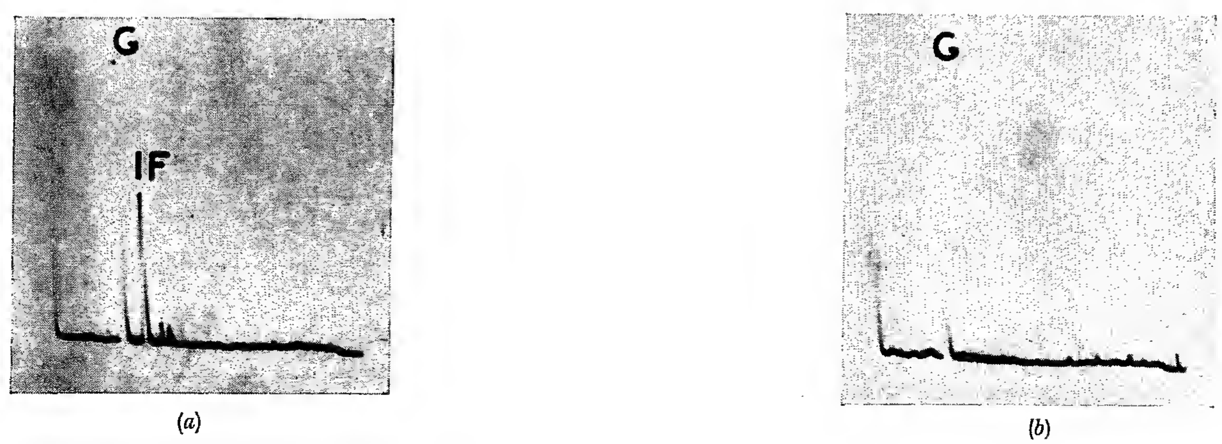


Fig. 9.—Photograph taken of a pulse transmission from a local transmitter received on spaced-frame aerials at Chelmsford.

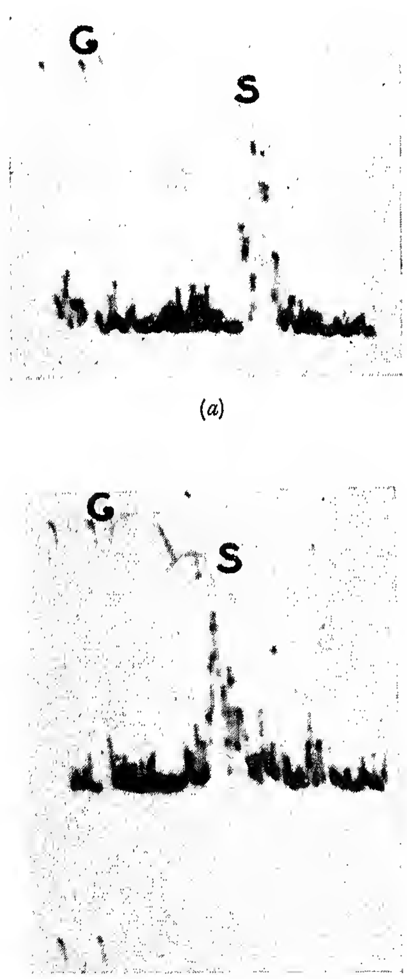
(*a*) Unbalanced, 1F echo showing. (*b*) System adjusted to balance-out the 1F echo.

Plate 3

(*a*) (*b*)

Fig. 10.—Transmission from Ongar on 9·275 Mc./s. with a beam on Melbourne, received on an Adcock aerial system with a heart diagram at Chelmsford.

(*a*) Goniometer setting 252° E. of N., scattering maximum. (*b*) Goniometer setting 72° E. of N., scattering suppressed.

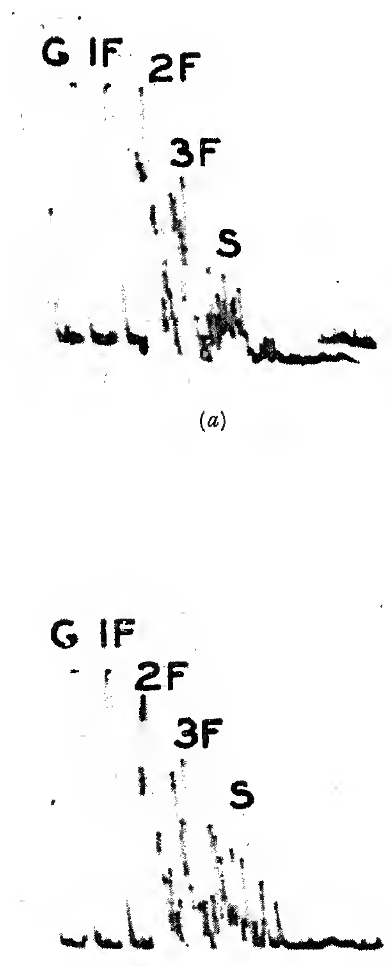


(*b*)

Fig. 11.—Ongar, 9·275 Mc./s., midnight, 29th July, 1936: records showing two groups of scattered signal received at Chelmsford on an Adcock direction-finding system.

(*a*) Goniometer setting 330° E. of N. First group (1F scatter) coming mainly from the north and nearly suppressed, second group (2F scatter) strong.

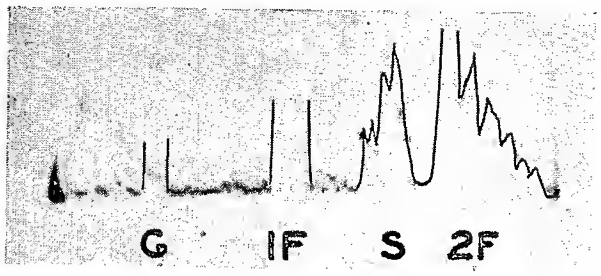
(*b*) Goniometer setting 150° E. of N. First group strong, second group coming mainly from the south and nearly suppressed.



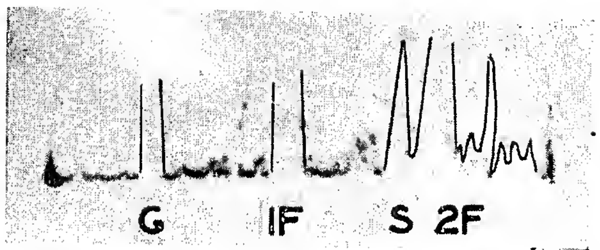
(*b*)

Fig. 12.—Ongar, 9·275 Mc./s., 1710 G.M.T., 28th February, 1936. Frequency below the critical frequency. F echoes present with distant scattering overlapping the 2F echo.

Plate 4



(*a*)



(*b*)

Fig. 19.—Ongar, 7·59 Mc./s., 0946 G.M.T., 9th October, 1936, showing distant-scattered group starting 100 km. before 2F echo.

The time-base is 6 millisec. The photographs have been inked in, as the traces on this fast time-base were too faint to reproduce satisfactorily.

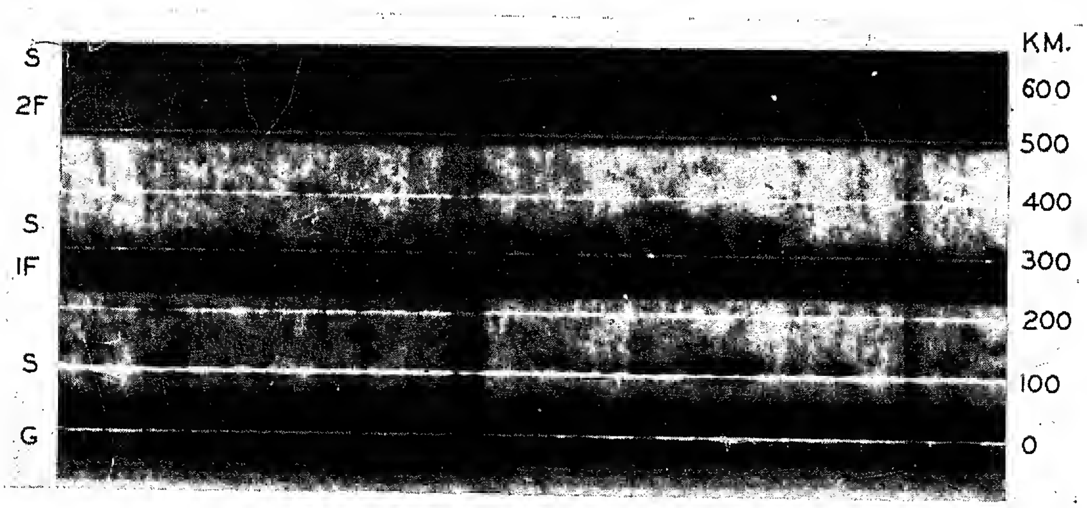


Fig. 24.—Ongar, 7·59 Mc./s., 1015 G.M.T., 27th November, 1936: *P't* record showing short-distance scattering, 1F scattering and 2F scattering. Overall time about 20 sec.

as that for which a ray for the same frequency just escapes through the F region, we have, according to simple ray theory,

$$\operatorname{cosec} \theta_s = \frac{f}{f_0}$$

where f_0 is the critical frequency at vertical incidence. Thus $d \propto f$, the frequency of transmission. The experimental results of Fig. 4 show this relation to be very approximately satisfied.

(b) Comparison of Ground and E-layer Scattering

In discussing whether the scattering occurs at the ground or well above, e.g. in the E layer, we first notice that there should be some fairly obvious differences between the two cases. If, for instance, the scattering sources are above the ground, then there is the possibility of direct illumination of these, even within the skip radius. Thus in Fig. 18(a) a scattering source at S_3 will be "illuminated" by a direct ray TS_3, and might contribute to a scattered echo arriving before the leading edge of the main scattered group produced by the mechanism already described. But it must be remembered that any such direct ray TS_3 will be very weak at S_3, not only because the energy radiated from T at such a small elevation is very small, but because of attenuation in the lower regions of the E layer if S_3 is sufficiently high.

Nevertheless, rays at higher elevation can encounter scattering sources, such as S_2, which will give rise to echoes. The short sporadic echoes observed are of such a nature.[5] Thus we can obtain scattering on the ascent of the rays, giving rise to the sporadic short-distance scattering at S_2, as well as on the descent of the rays at the edge of the skip zone at S_4.

The most definite evidence that the energy is scattered in the regions of the E layer is given by the experiments in which the frequency used is less than the critical frequency, so that normal F reflections are present. As the frequency approaches the critical frequency, the skip distance TS gets less and less. The height of the apex of the scattered ray remains more or less constant, and the skip ray TAS, as we may call it, becomes a more and more pointed arch, until in the limit as TS tends to zero it becomes a straight vertical ray. The time taken to traverse this vertical path, if scattering takes place at the earth's surface, is the time taken to traverse a path from T vertically to the ionosphere, down to the earth, and then back up to the ionosphere and down to earth again. This is exactly the time taken by the second-order F reflection.

If, however, the signal is scattered in the E layer before reaching the earth, the time of travel is less than for the normal 2F* echo by twice the time taken by light to traverse the vertical path from the ground to the height of the scattering source. Thus if we express the equivalent height of the leading edge of the scattered group by h_s and the equivalent height of the second-order F reflection by h_{2F}, then $(h_{2F} - h_s)$ is the height of the scattering source above the ground. We therefore have a direct method of detecting scattering sources which may exist above the ground, since, as mentioned above, in the later runs the density was often high enough to reflect the signals from the F layer at vertical incidence, and, as is seen from Fig. 12 (see Plate 3), the beginning of the scattered group is associated with the 2F reflection.

In practice the difference between the beginning of the scattered group and the 2F echo is not always easy to observe. A high magnification is needed to obtain the scattered signal, and noise sometimes obscures its start, since at nearly vertical incidence the strongest part of the scattered group is not usually at the leading edge but some little way within the group. Nevertheless, a large number of cases in which the scattering starts before the 2F echo has been recorded; examples are shown in Fig. 19 (Plate 4), and the distribution of the values of $(h_{2F} - h_s)$ is shown in Fig. 20.

In this case, in which the distant-scattered group is produced by scattering sources for which the reflection at the F layer takes place at or nearly at vertical incidence, the same scattering source in or above the E layer can give rise to both the short- and the long-distance

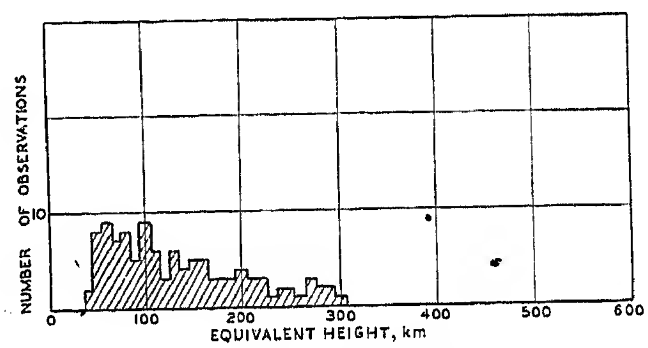


Fig. 20.—Distribution of equivalent height of scattering source measured by $(h2F - h_s)$, from observations made when the working frequency was below the critical frequency.

scattering, the first as the ray ascends, and the second as the ray descends, from the F layer. The heights of the scattering sources determined from the short-distance scattering measurements and those given by the $(h_{2F} - h_s)$ values should therefore be approximately the same. For any scattering source that is not vertically above the transmitter and receiver (assumed near to one another) the short-distance scattering measurement of equivalent height will give an over-estimate of the vertical height of the source above the ground, whereas the $(h_{2F} - h_s)$ measurement would similarly give an under-estimate of the height.

It should be noted that many cases occur in which the scattering starts at, or just after, the 2F echo. This is not taken to imply that the scattering takes place at the ground, but that the vertical reflections, for which $(h_{2F} - h_s)$ is finite, are often highly attenuated. Fig. 21 shows the envelope of the scattered signal measured on a high-power pulse from Ongar on a frequency of 7·59 Mc./s. and its relation to the normal F reflections. The initial parts of the scattered group are relatively weak, and thus the beginning of the group which should appear before the 2F echo may be below the noise level.

With these considerations in mind we can compare the distribution of the heights of the scattering sources (see Fig. 6) obtained from the short-distance scattering measurements, with the distribution of the $(h_{2F} - h_s)$ measurements on the distant-scattered group (Fig. 20).

* By 2F echo is meant one which is twice reflected from the F layer with an intermediate reflection at the surface of the earth.

The general agreement between the two is seen to be very fair, and suggests that the irregularities in the E layer are most likely the main source of the scattered signals of both the short-distance and the long-distance type.

(c) Relative Strength of Long-distance Scattering and 2F Echoes

Further evidence in support of the view that the scattering sources are situated in the E region of the ionosphere is supplied by a study of the relative strengths of the 2F echoes and the distant-scattered group. As an example, during a transmission on 8·005 Mc./s. from Dorchester on the 2nd September, 1936, at a time when the station was beyond the skip distance, the scattered echo was accompanied by multiple F echoes and weak sporadic short-distance scattering. In the early part of the programme from 0945 to 1000 G.M.T. reflection was very strong and echoes up to 5F were present. By 1030 G.M.T. the attenuation in the E layer had greatly increased, and the 2F echo was 25 db. down on the 1F echo, while higher orders than 3F had disappeared. Whereas the 2F echo had stood out strongly from the background of distant scattering, it was now only of the same order of intensity as the scattering. This observation is difficult to explain if we assume the scattering to take place from irregular objects on the ground, since the paths of the 2F echo and of the scattered signal would be of the same nature as far as their passage through the ionosphere is concerned. Each would have to pass through the E layer twice in the upward direction and twice in the downward direction, i.e. four times in all, and any increase of attenuation should affect each equally, so that the ratio of the intensity of the scattering to the 2F intensity should remain constant. If, however, the scattering takes place in the upper regions of the E layer, the scattered signal corresponds to only two passages through the E layer, one as the primary goes up to the F layer, and the other as the scattered signal itself comes down after reflection from the F layer. Thus the 2F echo, which still corresponds to four passages through the attenuating E layer, will decrease more rapidly than the scattered signal as the attenuation increases, until finally they are both of the same order of intensity.

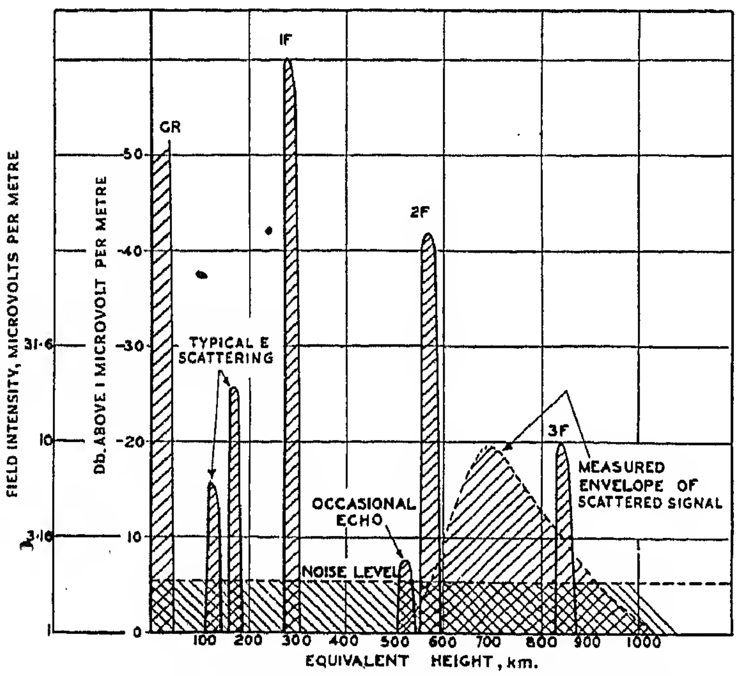


Fig. 21.—Diagram of field intensities of the various echoes obtained on a pulse transmission on 7·59 Mc./s. from Ongar, to show especially the envelope of the distant-scattered group

It was found that when the 2F echo was of the same order as the scattered group it was 26 db. below the 1F echo, i.e. its amplitude was only 1/20th that of the 1F echo. This ratio represents the attenuation due to a double passage through the E layer. In estimating the amplitude of the scattered signal we have to consider the attenuation suffered by the primary ray in passing through the E layer once, i.e. 13 db., and the similar attenuation as the scattered signal returns down through the E layer, but we have also to take into account the reduction in signal strength involved in the scattering process itself. This attenuation can be expressed in terms of an equivalent scattering coefficient γ defined as the ratio of the scattered intensity to the primary intensity, as if the scattering source were a partially reflecting surface. The total attenuation associated with the scattered signal is thus $26 - 20 \log_{10} \gamma$ decibels. The corresponding attenuation of the 2F echo is 52 db. due to the fourfold passage through the E layer, and, since under these conditions the 2F echo was of the same order of intensity as the scattered signal, we have $20 \log_{10} \gamma = -26$, i.e. $\gamma = \frac{1}{20}$.

Thus these observations not only decide in favour of the scattering sources being in the E layer and not on the ground, but they also afford an estimate of the scattering coefficient γ of the order of $\frac{1}{20}$. In terms of energy this implies that the scattering source transmits 399/400 of the incident energy, and only scatters back 1/400. Similar results have been obtained on the 7·59-Mc./s. transmissions from Ongar.

(d) Connection of the Distant Scattering with M-type and Abnormal E Reflections

It should be noted that when the scattering occurs at vertical incidence it differs only in name from the M echoes* studied by Ratcliffe and others, just as the short-distance scattering probably merges into abnormal E reflections. Now it is well known that M and F echoes can occur together at times when there is no E reflection, and similarly that E and F reflections can occur together without M, but it does not seem to be generally realized that any explanation of these observations in terms of a layer which is uniformly spread in the horizontal plane is untenable. The assumption that a discontinuity in the vertical gradient in the E layer will produce a partial reflection suffices to explain the occurrence of E and F echoes together, but, if there is a partial reflection on the way up to the F layer, we should expect at least an equal partial reflection on the way down again, and vice versa; i.e. whenever we get E and M echoes when F reflections are present, we should get E and M together and never one without the other.

If, however, we assume that the E layer is patchy, just as the scattering evidence would lead us to suppose, the

* By M echo is meant one which is twice reflected from the F layer with an intermediate reflection at the upper edge of the E layer.

difficulty is resolved. Instead of the E layer being uniform in the horizontal direction, we can picture it as containing a sheet of scattering sources forming a structure of high-density patches. Viewed from below these patches only cover a small fraction of the area, the system being in fact an open latticework of scattering centres. Such a sheet could produce E and F reflections without M, or M and F reflections without E, since a spherical wave travelling upwards will penetrate the gaps and give F reflections so long as any one of the high-density patches is not sufficiently widely spread to shield the F layer completely. The question whether E or M echoes will accompany the F reflections will depend upon the structure of the scattering clouds.

It is possible to construct examples where M and F echoes or E and F echoes occur alone, the circumstances depending upon the distribution of electronic density in the cloud. Consider, for instance, the case where the density is sharply defined above and tails off gradually below the densest region of the cloud, for which the equal-density contours are shown in Fig. 22. Waves approaching the clouds from below have to pass through a considerable region where the collisional frequency is so high that they may never reach a level where the density is sufficient to reflect them, while those approaching from above reach a sharply defined reflecting region where the collisional frequency is so low that good reflection can occur. F and M reflections will then occur without E reflections. A sharply defined lower surface and an ill-defined upper surface in the cloud will similarly favour E and F reflections without M. Observational results which are impossible to explain on the hypothesis of a layer which is uniform in the horizontal plane, are thus explicable on these lines.

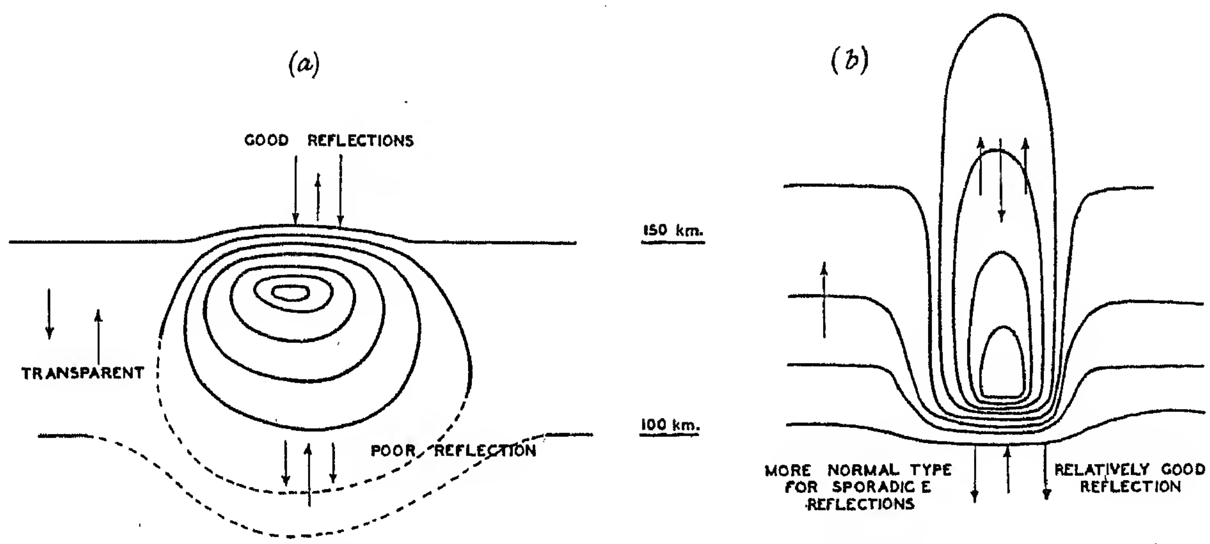


Fig. 22.—Diagram showing the density contours in ionic clouds which would produce (*a*) simultaneous F and M echoes without E echoes, and (*b*) F and sporadic E echoes without M echoes.

(e) 1F Type of Scattered Echo

This picture of a scattering source as a high-density cloud in the E region suggests another possible type of scattering, illustrated in Fig. 23, in which an echo reflected from the F layer is slightly deviated in passing through the scattering layer to produce a total path somewhat longer than the normal 1F echo* path. This delay beyond the 1F echo cannot be great, because in conditions where the scattering source is laterally much displaced from the receiver, the path from the source to the receiver through the E layer is so oblique that the scattered signals will suffer great attenuation.

Such scattered echoes have been regularly observed in the transmissions on 7·59 Mc./s. from Ongar, where the working frequency is generally less than the critical frequency for the F layer. A good example is shown in Fig. 24 (Plate 4). They appear as a set of sporadic echoes just beyond the 1F echo. This type of scattering may obviously also occur as the ray passes through the E layer on its upward journey, but the fact that the echoes are slightly delayed on the 1F echo makes it highly improbable that the scattering sources are in the F layer, as this would imply that the rays penetrate beyond the

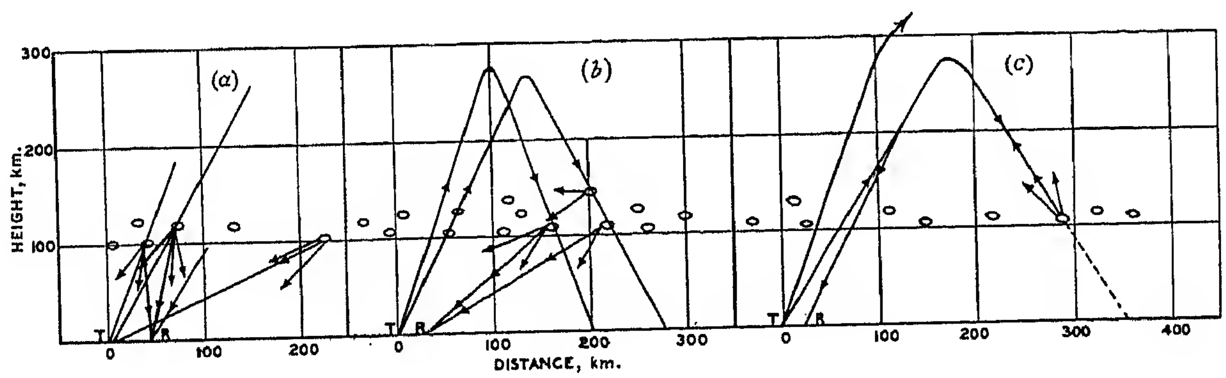


Fig. 23.—Diagram to illustrate the three main types of scattering received at a point R near a transmitter T.
(*a*) Short-distance E scattering. (*b*) 1F scattering. (*c*) 2F scattering.

* By 1F echo is meant one which is simply reflected once at the F layer.

level at which the 1F reflection itself takes place. Nor is it likely that these echoes are in reality direct short-distance scattering at very oblique incidence, corresponding to their relatively long time-delay, as such an oblique path through the E layer would involve high attenuation.

This type of scattering has also been observed on the 9·275-Mc./s. transmission of the 40-kW transmitter at Ongar at times when the 1F echo has been absent. It is obviously not necessary that the 1F echo should be present, as the primary ray producing the scattering can have been reflected at oblique incidence from the F layer; but the working frequency cannot be much greater than the critical frequency at vertical incidence, for the lateral distance of the scattering source would become too great to give appreciable scattered signals at the oblique incidence involved.

The 1F scattering appears to be very highly attenuated in the daytime. At night, however, when the E layer attenuation is greatly reduced, the 1F scattering should be readily observable. Now it has already been noted that the observations made at night indicated the existence of two distinct groups of scattering, and the first of these can generally be identified as 1F scattering. Observations made when the two distinct groups of scattered signal were present at night-time are grouped together in Table 2, together with data regarding the ordinary and extraordinary critical frequencies obtained from vertical-incidence $P'f$ curves taken at the same time. All the observations of scattering refer to tests made on the 9·275-Mc./s. transmitter at Ongar.

In many cases the equivalent distance of the 1F scattering is slightly larger than the 1F equivalent height, which is in accordance with the mechanism proposed. Similarly the 2F scattering-distance is approximately twice the 1F scattering-distance, which is also to be expected. On these grounds the near group of the scattering can be definitely identified as of the 1F type. It cannot be of the 2F type since the delay time is much too small, and the second more delayed group can in certain cases be definitely identified as the 2F scattering. It will be seen that in every case except the last the critical frequency is only slightly lower than the working frequency, and the conditions in which 1F scattering is to be expected are thus satisfied.

(f) The Intensity of the Scattering as a Function of Frequency

There is a further observation which affords a criterion for deciding whether the scattering sources are on the ground or in the E layer, namely the measurement of the intensity of the scattering and its variation with frequency. If conducting or semi-conducting objects comparable in size with the wavelength, such, for instance, as steel girders, houses, trees, small hills and similar irregularities on the surface of the earth, were responsible for the scattering, the scattered energy would obey Rayleigh's scattering law and increase as the fourth power of the frequency. Sea waves, if of sufficient amplitude, would afford a scattering source of the same type, and in practically all such cases the intensity of the scattering would increase rapidly with the frequency.

Now curves have already been given in Figs. 14 and 15 showing the intensity of the scattering for equal power outputs as a function of the wavelength, and these curves indicate that the intensity increases rapidly with increasing wavelength, i.e. with decreasing frequency.

Table 2

Date (1936)	Critical frequency (Mc./s.)		Equivalent height of layer* (km.)	Equivalent distance (km.) of 1F scattering	Equivalent distance (km.) of 2F scattering	Ratio (2F/1F) of scattering distances
	Ord.	Ext.				
3rd June				580	1 200	2·07
10th June				400	800	2·00
10th June	6·75	7·4	400	500	900	1·80
1st July	7·96	8·51	320	1 000	1 800	1·80
2nd July				1 050	2 000	1·90
8th–9th July				400	1 650	4·12
	7·10	7·80	350	340 } 390		
				320	1 000	2·93
				500	1 000	2·00
15th–16th July				430	900	2·09
	7·07	7·75	350	450 } 415	900	2·00
				380		
				400	1 100	2·75
29th–30th July				800		
		5·15	400	850 } 800		
				800	1 250	1·56
				750		
					Av.	2·25

* This was measured on a frequency well below the critical frequency, where the $P'f$ curve becomes relatively flat.

These observations are thus in direct opposition to the idea that the scattering occurs from irregularities on the ground. If, on the other hand, the scattering is caused by ionic clouds in the E layer, we should expect an increase in the intensity of the scattering with increasing wavelength of the type observed.

The author has discussed the mechanism of this type of scattering in a previous paper,[16] in which he showed that scattering from ionic clouds is analogous to the scattering of α-particles by heavy molecules, leading to Rutherford's law of scattering. In this theory the ionic cloud is assumed to be spherically symmetrical, with a maximum density at the centre and the density dropping off with distance from the centre according to the law $e^{-r/a}$, where r is the distance from the centre and a is a constant which is large compared with $\bar{\lambda}$, the wavelength of the incident ray in the surrounding ionized medium. It is then shown that the ratio of the scattered to the incident radiation is proportional to the density at the centre of the cloud and to $(\bar{\lambda})^4$, while except for the case where θ is very nearly zero the polar diagram is given by a $\operatorname{cosec}^4 \theta/2$ law.

With this model the scattering is a minimum when $\theta = 180°$, i.e. the energy scattered with a small angular deviation should be very much greater than the energy scattered backwards, while since $1/\bar{\lambda}$ for a given wavelength λ in free space is proportional to the group velocity, the $(\bar{\lambda})^4$ law corresponds to the fact that in the analogous case of particle-scattering the slow particles are much more scattered than the fast ones. When the working frequency is well above the critical frequency of the layer, $\bar{\lambda}$ approximates to λ, and the backward-scattering should be proportional to the fourth power of the wavelength employed, in direct contrast to the Rayleigh scattering law.

Although this model represents a very ideal case, a little consideration will convince one that an increase of wavelength will increase the scattering from almost any kind of ionic cloud. Physically it is fairly obvious that a cloud will offer little obstruction to a very high frequency, and that the obstruction and amount of scattered energy will increase as the wavelength is increased. For purposes of comparison the fourth-power law has been plotted in Figs. 14 and 15. The actual scattered signal will depend upon the distance of the scattering source and upon the attenuation suffered *en route*, so that the observations do not correspond completely with the intrinsic scattering which the fourth-power law represents. But as the attenuation increases with the wavelength, any corrections applied to the observations on this account would increase the intrinsic scattering on long as compared with short waves, and make the observations deviate still further from the Rayleigh law of scattering.

Figs. 14 and 15 show that the observed intensities of the scattering decide in favour of scattering from ionic clouds and not from ground irregularities, and, assuming this, the theory shows that the average size of the clouds could be obtained if measurements on the polar diagram of the scattering could be made. As the law relating the density at any point within the cloud to the density at the centre has been taken to be of the form $e^{-r/a}$, a may be regarded as a measure of the mean or equivalent radius of the cloud. The theory shows that the ratio of the forward scattering to the backward scattering is $(2\pi a/\bar{\lambda})^4$, and thus a measurement of this ratio would give a value of a.

So far, attempts to measure the polar diagram of the scattering have been more or less unsuccessful, as it is difficult to devise an experiment on a reasonable scale to give this diagram unequivocally. In theory, the transmission from a beam transmitter giving a moderately well-defined scattering source could be investigated by taking a receiver round a circle centred on the source with a radius equal to the skip distance. As this may be of the order of 1 000 km. this would entail a journey of some 6 000 km. The comparison of the intensities of the 1F and 2F scattering at night should give the ratio of forward to backward scattering with some measure of accuracy, since the complications due to attenuation are largely reduced at night. The average angle of deviation of the 1F scattering will be less in proportion as the skip distance is smaller, and can be approximately computed from the vertical-incidence $P'f$ curve. Some tentative experiments have been made which indicate that the 1F scattering in such circumstances is considerably stronger than the 2F scattering.

(8) RÉSUMÉ AND GENERAL CONCLUSIONS

The various lines of evidence discussed above lead to two definite conclusions, (i) that there is a region of very marked ionic irregularity in and above the E layer, and (ii) that the types of scattering observed, i.e. the short E, the 1F and the 2F scattering, all originate in this scattering layer. In support of the first conclusion, we have the results provided by the short-distance scattering, which patently indicate an irregularity in time. The experiments with the spaced frames show that the reflected radiation from the sporadic E region is not coherent, and finally the observations on E, M and F echoes can only be explained on the assumption of ionic clouds in the upper part of the E layer. The identification of ionic clouds in the E layer[5] completely confirms this.

In support of the second conclusion, it may be noted that the 1F type of scattering can only arise in regions above the earth, and the evidence that the 2F scattering often arrives before the main 2F echo is conclusive. The relative attenuations of the 2F echo and scattering support this view, and the intensity observations indicate that it is highly improbable that the scattering arises from irregular objects on the earth's surface, but that it is most probable that it takes place at ionic clouds.

As has been mentioned, a large amount of evidence exists that the E layer has an irregular structure both in space and in time. The experiments show that clouds are formed in the E region of the ionosphere, and that they rapidly disappear in the course of a few seconds. During any period comparable with the life of the cloud, 0·5 to 10 sec. and in many cases even longer, there will probably be at least one cloud, corresponding to one sporadic echo, in an area enclosed by a circle of radius approximately 100 km., i.e. an area of approximately 30 000 km^2. At times when the activity of the scattering is great and there are many short-distance scattered echoes occurring simultaneously, the cloud density will be greater, but the figure given is a rough average. As

regards the size and total ionic content of the clouds it would be rash to make a statement, because it depends so much on the shape of the cloud, but we know, as a matter of measurement, that the intensity of the rays scattered from such clouds is of the order of 20 to 40 db. below the intensity of the primary radiation. For the spherical model of the cloud we have assumed, this would imply that the total number of ions in the cloud is of the order of 10^{16} or 10^{17}, on the assumption that the scattered radiation is 1/2 000 of the primary radiation.

The existence of these ionic clouds in the E layer of the ionosphere and their general nature, as deduced from scattering experiments, raise some very interesting speculations as to the physical agencies and processes by which the clouds are formed and then disperse again, but we cannot enter into this aspect of the problem here. From the engineer's point of view the most interesting and important aspect of the existence of these ionic clouds is the bearing they may have on transmission problems by reason of the scattering of incident waves which they produce, and by means of which their existence has been deduced.

When the receiving station is within the skip zone round the transmitter, no primary radiation will be received, and the scattered signals become all-important because they are the only ones; the presence of weak signals giving no bearing, or one that may be entirely wrong, is wholly explicable in terms of scattering. In long-distance transmissions beyond the skip distance, the primary radiation is inclined to swamp the scattered signals, but the effects of this scattering may still have an important bearing on the transmission. Such effects will include lateral and vertical deviations of the ray path which may spoil the directional stability required for the successful operation of aerial systems, such as the "M.U.S.A.," designed to mitigate the distortion produced by multiple-echo reception.

In direction-finding work, the irregularities in the path limit the accuracy obtainable, since the scattering produces an actual lateral deviation of the ray, which will thus affect the aerial system, even though it may be free from polarization error like the spaced frames described earlier. Details of the deviations from the true great-circle bearing obtained in practice at Chelmsford on transmissions from Dorchester are given elsewhere.[17] If accidental variations of a degree or two are possible, either laterally or vertically, in a single reflection, it is only a matter of statistics, on any theory of the mechanism, to calculate what the accidental variations will be after n reflections. If the deviations are all accidental, then the root-mean-square deviation should increase as $\sqrt{n}$.

This has been tested by comparing the root-mean-square deviation for the first-order reflection with that for the second-order reflection. In a test in which a pulse transmission from Dorchester on the 19th March, 1937, was received at Chelmsford, the root-mean-square deviations for the 1F and 2F reflections were $0 \cdot 897^\circ$ and $1 \cdot 262^\circ$ respectively; the square of the ratio, which should be 2, is actually $1 \cdot 98$.

The scattering effect of the ionic clouds may also include the possibility of echoes becoming split, even where no magneto-ionic effects are involved, since rays may reach the receiver by different paths depending upon whether they encounter a cloud *en route* and upon the degree of scattering involved. Thus a more complex echo pattern may be produced than would be expected on the simple ray theory alone. Such effects, though possibly not very serious in practical transmission, become important when one attempts to explain the echo pattern obtained at long distances.

In a transmission between England and Australia where the number of multiple echoes may be nine or even as many as twelve, the echo pattern will be very complex and difficult to interpret when the scattering effects are added to the complications caused by oblique incidence and magneto-ionic splitting. Moreover, as the angle of arrival between a high-order echo and the next higher order, e.g. the 9th and the 10th, is only about 2°, and the r.m.s. deviation in the vertical plane due to scattering for such high-order rays would be of the order of 3°, the accidental angular variation of any two adjacent rays may be greater than the difference between the mean values, and the rays will be inextricably mixed. The separation of the individual echoes for practical purposes or for analysis will present great or even insurmountable difficulties. This is what has actually been observed in transmissions received at Chelmsford from Melbourne. Instead of the echo pattern presenting a complicated but defined set of multiple echoes, it was a jumbled mountain range of peaks in which it was impossible to identify any stable system of echoes.

Enough has been said to show that the effect of scattering is of considerable importance in the analysis of long-distance transmission phenomena, which cannot be adequately understood without a knowledge of the mechanism by which the scattering is produced; and the aim of this paper has been to present in as complete a form as possible the results and conclusions obtained after many years of study of the subject.

(9) ACKNOWLEDGMENT

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DISCUSSION BEFORE THE WIRELESS SECTION, 7TH FEBRUARY, 1940

Mr. H. L. Kirke: The paper is of very considerable interest and is the outcome of many years of theoretical study and experiment. The importance of the paper lies largely in the fact that proof of the source of scattering has been obtained. It brings out very clearly the great importance of the pulse method of exploration of the ionosphere, which has been in use for many years and superseded the original method of changing the wavelength.

The author suggests that very low-angle radiation does not penetrate the E layer, and therefore does not reach the F to get reflected back from the E layer. In this connection can the author state what is the lowest-angle radiation that can be transmitted through the E layer, and does this depend upon wavelength? This question has a bearing to a large extent on the design of transmitting aerials for long-distance communication.

Mr. R. Naismith: On page 548 the author defines scattering in terms of ionospheric structure. From Fig. 6 we see that the maximum number of these scattering clouds occur at a height of 100 km. We also know from other evidence that intense ionization occurring at 100 km. and extending over large areas is capable of effecting the transmission of radio waves of wavelengths less than 10 m. to great distances. It follows, therefore, that the small ionic clouds causing the scattering are frequently situated within larger clouds causing reflection. We can thus have on the same wavelength, at the same time, both scattering and reflection from the same place in the ionosphere. The known imperfection of the ionosphere as a medium for radio transmission implies scattering and it therefore seems unnecessary to define the term "scattering" more explicitly.

The author has made observations on the scattering of radio signals over a number of years. It would therefore be interesting to know whether he can attribute the apparently continuous production of these small ionic concentrations to a particular agent and whether their production varies during the sunspot cycle.

Mr. W. L. McPherson: The effect of carrying on a long-continued study such as is described in the paper is to make the investigator over-emphasize the importance of the phenomena being studied, and this may be why the author is unduly pessimistic with regard to the effect of scattering on the value of highly directive aerial systems. It is well recognized that in practice the full theoretical gain of a narrow-beam aerial array is seldom realized; nevertheless, the average gain of such an aerial, taken over the useful hours for the wavelength for which the aerial is built, is sufficiently high to have considerable financial value. This is particularly the case when the beam can be steered automatically, as in the later forms of the M.U.S.A. system; and the author's arguments, if accepted, would in fact appear to constitute a reason for considering the possible extension of the M.U.S.A. principle to horizontal as well as vertical steering, rather than for discarding the principle altogether. I am not quite clear, however, as to how the author arrives at such a complete condemnation of high directivity. He states in the paper that the level of the scattered radiation is of the order of 20 to 40 db. below the primary radiation level, and this would appear to leave a normal ray of quite appreciable amplitude. I should welcome further explanation of this point.

The paper does not mention what was the state of polarization of the radiation transmitter during the pulse measurement. It would be worth while adding this information, and also any information which may have been recorded as to any peculiarities in the state of polarization of the received scattered waves.

The author states that the scattering effect increases with the wavelength, from which one might infer that on very short waves scattering is almost negligible. We cannot, however, expect that the scattering trouble will disappear altogether on the ultra-short-wave band, even although transmission does not involve reflection from the ionosphere. There is another factor to consider, particularly when we get down to wavelengths of the order of 2 m. and shorter. Tests in America lasting over some months showed that 2·5-m. communication was governed to an appreciable extent by reflection from a lower stratification in the sky, which extends over a wide area and is most clearly marked in the colder months of the winter. If reflection phenomena occur on these wavelengths one might also expect scattering. This might have some bearing on the fact that during the operation of the 17-cm. micro-ray station at Lympne there were three occasions on which the communication, otherwise perfectly good, suffered from a peculiar flutter effect. Sometimes this was audible only at one terminal, sometimes at both. Generally speaking, the signal was stable and the flutter was superimposed. There was no inter-modulation, and quality remained unaffected. A rather similar effect has also been reported in connection with the 70-cm. wavelength experiments carried out in the Mediterranean during the winter of 1931. Possibly on such occasions scattering was being caused by small clouds or patches of stratification at a fairly low level. It would be interesting to have the author's comments on this matter.

Mr. W. Ross: There are several points in the paper which call for comment, and in particular one connected with the rejection of the theory of scattering by sources on the ground. Part of the author's argument is based

on the assumption that scattering from sources on the ground would be inversely proportional to the fourth power of the wavelength. But the Rayleigh law of scattering only applies to objects very small compared with the wavelength, whereas the paper refers to scattering objects on the ground whose dimensions are comparable with the wavelength. It can be shown that scattering from terrestrial objects of a size comparable with the wavelength might be expected to reveal an intensity which increased rather than decreased with wavelength. I do not suggest, however, that this in any way detracts from the great bulk of evidence in favour of the theory that the scattering centres are in the E region.

I should welcome another expression of opinion from the author on the importance of scattering in the phenomena of lateral deviation of echoes reflected from the F layer. Some of his slides showing the bearing of the station at Dorchester received at Chelmsford revealed that the lateral deviations observed on F echoes, besides showing erratic moment-to-moment fluctuations, also showed rather long-period changes in bearing which I find difficult to explain on any theory based on scattering. I formed the impression from the author's remarks in presenting the paper, as well as from its concluding sections, that he is of the opinion that all deviations of F reflections are in some way connected with the scattering region in the E layer.

Finally, I think that as a fitting conclusion to such a long investigation on the subject of scattering some experiments should be made with a view to discovering more definitely the relative importance of scatter as compared with true reflections. There is no very great bulk of evidence yet available to show whether scattering is in fact important when transmission is being effected by normal reflection from the F layer.

Dr. R. L. Smith-Rose: I presume it is not impossible that in addition to the normal reflections a further set of echoes might be received from the first scattering source, the rays from which have subsequently suffered two reflections, one from the F layer and the other from the ground intermediately.

This paper possibly tends to destroy the first impressions created by the simple explanation of the skip distance of ray transmission. It is frequently assumed that within the skip distance there is little possibility of receiving signals from a transmitter, an occurrence which might have an obvious strategic value. The results given in this paper, however, suggest the possibility of reception within the skip distance, but it is important to bear in mind in this connection the order of magnitude involved in this work. The author shows that the level of the scattering signal is 40 db. or so below the level of the direct transmission, and he has had to use high-power transmitters in order to get sufficient intensity for recording the scattered echoes. It seems a reasonable deduction from this that, using a suitably weak transmitter, it is still possible to transmit effectively to distances well beyond the skip range with the certainty that reception within that range is too weak for reliable communication.

I should like to point out that although the author's records show these echoes from scattering sources to be very intermittent, it is nevertheless possible to receive signals sufficient for intelligible reception from broadcasting stations which are operating on the wavelengths and under the conditions described in the paper. I am not clear whether the conclusion to be drawn from that is that the reception of intelligible signals arises from a sort of integral effect of all the scattered echoes received at any time, but if so it is a little surprising that the signals received are as intelligible as they are.

I rather share with Mr. Ross the suspicion that the author has dismissed a little too easily the possibility of scattering taking place from the ground, particularly when I read his remarks to the effect that girders and trees cannot act as scattering sources. Trees, for example, can be regarded as acting as earthed aerials, and the natural wavelength of trees in this country is well within the wavelength band used by the author. It would not be expected that the scatter radiation from these trees would follow the fourth-power law which he suggests as a reason for rejecting scattering from the ground.

The author deduces that the scattering coefficient is of the order of 1/20th, and then states that the remaining 19/20ths of the radiated energy is transmitted through the layer. The fact that this coefficient is 1/20th implies that 1/20th of the energy is scattered back in a direction which will give signals at the receiver, but it does not follow that the remainder is transmitted through the layer; the whole of the 19/20ths might be scattered at random in various directions from the top of the layer.

Mr. G. Millington: There seems to be some slight misunderstanding about the difference between the "near-in" and the distant scattering, and, as I have been working under Mr. Eckersley during most of the time that this research has been going on, I should like to take the opportunity of underlining the distinction between the two types which he has described. Fig. 1, Plate 1, which shows a group of morse dots, is essentially a picture of distant scattering, in which the sharp leading edge of the scattered dot is considerably displaced from the beginning of the ground-ray dot. When we first examined these dots, we noticed that there were occasional short bursts of scattering coming in at an "equivalent height" of only about 100 km. This "near-in" scattering was much more intense than the distant scattering, and when pulses were used instead of dots it took the form of individual echoes, which were sporadic in occurrence and usually lasted for about 0·5 sec. Fig. 2, Plate 1, shows both types of scattering. The "near-in" or short-distance scattering is scattered back directly from the under side of the E region, while the distant scattering is scattered back obliquely from the upper side of the E region and is returned to the ground by reflection from the F layer, as is shown in Fig. 18.

The more or less continuous signal obtained within the skip zone from Daventry is mainly due to the distant scattering, which, although made up of a series of echoes rapidly changing in detail, is an integrated effect due to the fact that the scattering sources illuminated by the primary radiation start at the edge of the skip zone and extend a long way beyond. They thus present a large target, and they give rise to so many individual echoes, each only of short duration, that the resultant is a continuous and coherent signal.

Dr. E. H. Rayner: Is there any correlation between scattering and magnetic storms? Sometimes storms of a definite intensity, as measured by their exceeding certain arbitrary values of the variability of magnetic elements, occur once a month, and sometimes 2 or 3 months pass without any; but during the last month we have had several within a week, and it would be interesting to know whether scattering effects are linked with these conditions. Has scattering any correlation with sudden fade-outs? Does it persist after a fade-out has taken place?

How important is scattering, or its effects or causes, in relation to commercial transmission? Does it only occasionally affect the quality of the transmission?

Mr. J. A. Smale: I should like to ask what is the commercial value of the findings reported in the paper. Probably there are cases where use could be made of scattering in commercial radio transmission, but it is doubtful whether these occur sufficiently often to make it worth while. There have been a number of cases, as, for example, in communication between England and Japan on the 26-m. wave, where the maintenance of communication has been due solely to scattered signals. Cases occur where the direct transmission route is temporarily closed, communication being maintained by relay stations, and it would save a great deal of trouble and expense if we could find an alternative to the use of such relay stations.

Mr. T. L. Eckersley (*in reply*): In answer to Mr. Kirke, I would say that the lowest angle at which a signal can be transmitted through the E layer, a matter which much concerns the Empire broadcasting, is not really related primarily with scattering but with the properties of the E layer in bulk. When the critical frequency is known, the lowest angle of penetration of the E layer is also known. The presence of abnormal E, which probably has a sharply defined under-surface and which is irregular and akin to the scattering clouds, rather obscures the issue, and makes the critical frequency difficult to observe. When such abnormal E is present, it is practically impossible to specify by calculation the lowest angle of penetration. This is because it is patchy, and may or may not be penetrated even at vertical incidence. A practical point is this: from the evidence we have obtained, I do not think there is any appreciable signal beyond about 1 000 km. which has been transmitted by reflection between the abnormal E layer and the earth.

I rather gather from Mr. Naismith's remarks that he considers that the irregularities in bulk of the E-layer ionization are sufficient to account for the effects observed, and that there is thus no need to coin a new name, i.e. "scattering," for them, or to investigate them at all. Sporadic or abnormal E is an irregularity in the E region of the ionosphere and has been investigated. Yet though the scattering irregularities and the sporadic E may be akin, as suggested on page 551, there are many differences, and we cannot say that investigations under the name of sporadic E have yielded such a wealth of information about these irregularities as the investigation carried out here under the pseudonym of scattering. I would never insist that the nicely rounded spherical clouds used as a model for scattering are actually to be found everywhere in the E layer exactly to specification, yet many of the effects of irregularities in the E layer can be adequately explained in terms of such a simple model.

Although we have studied scattering throughout the period of a sun-spot cycle, we are not in a position to say whether the amount of scattering varied appreciably throughout this period. Improvements in the technique of obtaining and recording the E scattering were being made all the time. Thus the observations do not form a continuous uniform series. It is therefore impossible to compare the earlier and later results. There is, however, no obvious indication that the scattering changed throughout the sunspot cycle. There is, of course, the fact that the scattered signals on Bodmin and Grimsby (both approximately 16 m.) were not heard during the sunspot minimum, but this might be attributed to the escape of these signals through the less dense layer, were it not for the fact that long-distance transmission was maintained on these wavelengths. In view of all the evidence (scattering *was* present on the longer waves), I am inclined to attribute this absence of scattering on 16 m. not to the absence of scattering clouds but to the attenuation resulting from the increased length of path over which the scattered signals had to travel.

Mr. McPherson seems to think that I have got a scattering bee in my bonnet, and that, in virtue of attending to scattering and scattering only, I have tended to exaggerate its effects. This is by no means the case. I hesitate to set down all our activities as to do so would take up too much room. I can only invite Mr. McPherson to see our records, which are by no means exclusively concerned with scattering. I think he has misunderstood my attitude towards the M.U.S.A. system. It is no wholesale condemnation as he seems to think. It was with the purpose of finding out the directional stability of long- and short-distance rays, and its relation to the M.U.S.A. system, that many of the experiments with spaced frames and scattering were initiated.

It is now well known that the ray directions vary very considerably—on Dorchester they may vary $\pm 5°$ or more, both in vertical angle and in azimuth. There can be little doubt that the main variability is due to irregularities in the E layer. Such variability is definitely a serious limitation to the use of very high directivity. Where this variability is such that no two adjacent rays can overlap, it cannot set much limitation on the use of the M.U.S.A. system. (This state of affairs probably occurs in the America–England system.) At extreme distances, for example Australia–England, the directional variability is greater than the angle between adjacent rays, and these become so inextricably mixed that it is impossible to select any one by highly directional methods. This is illustrated by the echo pattern of pulses from Australia. It is a jumble of peaks with no definite ray among them. No highly directional aerial will be of any use in selecting a single ray and avoiding selective interference effects. The limitation to the M.U.S.A. system is a matter of distance. To quote the fact that the intensity scattered back over 180° is some 40 db. down on the primary radiation is not entirely relevant. We are dealing with the case of long-distance transmissions and with energy or rays deviated over a few

degrees or so. The mechanism proposed allows the rays to be deviated over a few degrees without much loss.

With regard to ultra-short waves, I very much doubt whether the ionosphere has any appreciable effect at all. In the example of the Lympne–St. Englevert 17-cm. transmission, it seems very unlikely that a signal which has travelled 100 km. up to the ionosphere and is very weakly reflected back should appreciably affect the reception of the concentrated beam projected towards the receiver. It seems to me much more likely that the effects observed are due to irregularities in the refractive index of the lower regions of the atmosphere which have been proved to produce violent fading.*

Many polarization experiments were made, but for the sake of brevity these are not included in the paper. Transmitting aerials of various types have been used, i.e. vertical aerials, beam aerials, etc., but most of the later results on 7·59 Mc./s. were obtained with a horizontal doublet radiating vertically. This gave us about a 20 db. gain on the strength of the near-in scattering over a half-wave vertical doublet. The polarimeter was used on many occasions to measure the state of polarization of the scattered waves. The majority of such experiments have shown that the scattered signals give no balance on the polarimeter, and recent experiments using high-speed recording show that this is because the resulting polarization ellipses pass through many configurations in less than half a second.

I am glad to see that Mr. Ross and others have realized the difficulty of proving that the scattered signals come from the E layer and not from the ground. I must confess that for a long time I could find no conclusive proof and that I am still not absolutely certain that a very small proportion may not be scattered from irregularities on the ground. The main argument for believing that scattering comes from irregularities in the E layer are given in the paper, and, although singly they may not be so, when taken together they form a body of evidence which—at least to me—is very convincing. Mr. Ross's argument segregates one aspect, and perhaps for this reason carries more weight than it should. It is perfectly true that ground objects which may scatter waves are not all small compared with the wavelength, so that Rayleigh's inverse fourth-power law does not necessarily hold. In spite of this, it is very unlikely that the energy scattered will actually increase with the wavelength. This is a property of ionic clouds.

It is quite conclusive that part of the scattering comes from the E layer: the short E scattering and the location of irregular clouds in the E region are convincing proof. A wave which is wholly reflected from the E layer, i.e. which does not penetrate, would, if all the scattering were from the ground, show a perfectly clean first echo and an irregular second echo if objects on the ground were the cause of the scattering spread. Actually the first echo is just as irregular as the second, proving that the scattering irregularity is associated with the E layer and not with the ground. A great deal of accumulated evidence of this sort has convinced me that the major part of the scattered signals comes from irregularities in the E layer. The ever-present scattering from points over the sea, which is sometimes calm, shows that only an unappreciable part of the scattering can come from objects on the ground. This and other evidence constitutes the justification for neglecting the ground scattering.

Finally Mr. Ross suggests that it would be a fitting conclusion to the work on scattering if I could give an estimate of the relative importance of scattering as compared with true reflections. No doubt an evasive answer is expected, for it is difficult to give an exact meaning to "true reflection." Nevertheless, I will venture to give a numerical answer and state that just outside the skip distance approximately 96 parts of energy in 100 are true reflections, and the remaining 4 in 100 are scattered energy. This numerical description does not give a true measure of its importance. Scattering irregularities are of importance in direction-finding, since lateral deviations of the order of 4–5° are produced. They are also sufficient to mix up the rays in long-distance transmission, and the effects are, perhaps, more important than the relative energies might lead us to expect.

No doubt low-powered stations fail to afford any communication within the skip distance, and have, as stated by Dr. Smith-Rose, an obvious strategic value. Nevertheless, it would be a communication that would have to be very carefully used: a very small increase in ionic density would make a large difference in the skip distance, and it is not always easy to ensure that scattered signals should not be strong enough to be intelligible. A watch on the ionosphere would have to be kept. Stations of ordinary commercial power always seem to produce adequate signals in the skip zone, even though the scattered signals may be as much as 40 db. down on the main signals. It is only the short scattering (100 to 200 km. equivalent height) that is really intermittent. Long-distance scattering taps such a large area that signals are practically continuous, and the integral effect of all these signals produces an intelligible signal, but with a peculiar but easily recognizable timbre. Rapid flutter-fading is often produced, but even in this case the signals are usually intelligible. As stated in my answer to Mr. Ross, I do not think that ground scattering has been lightly dismissed, although a final conclusion makes it appear as if it had been.

Mr. Millington does well to emphasize the difference between short and long scattering. I think that, although mentioned in the paper itself, a further reference to it will make the matter clear and bring out the essential features of scattering.

In answer to Dr. Rayner, there is a very marked relation between bright hydrogen eruptions and scattering clouds. We have been aware of this for over two years, but have not had time or opportunity to publish the results. High-power transmissions, in which scattering clouds could be observed, only took place for four hours a week, and the probability of obtaining a fade-out during this time was small. Nevertheless, in the series of tests since 1936 there have been 15 occasions on which a fade-out occurred during the transmission period. For the activity of scattering we give a character figure 1, 2 or 3 (similar to the magnetic character figure), 3 representing

* A. R. Englund, A. B. Crawford and W. W. Mumford: *Bell System Technical Journal*, 1938, **17**, p. 489.

the most active state of the clouds. Of these 15 fade-outs, 9 were accompanied by extreme scattering activity of character 3, while of the remaining 6, 4 were less intense fades not cutting off long-distance signals entirely. Two of the fades were so intense that even the scattered signals were cut off for a period coinciding with the bright hydrogen eruption, although just before and after the scattering activity was very great. During the period 6th November, 1936 (when recording in a uniform manner was begun), to March, 1938, 11 of the 121 programmes had a scattering character figure 3. Seven of these were on the occasion of fade-outs. If the two effects had been random and uncorrelated, the number of coincidences would have been $0 \cdot 64$, which is less than a tenth of the actual number observed. Most of the programmes were observed visually, although a small part of the time was devoted to recording them. Thus we have only one photographic record of a minor fade-out, in which the F reflection was suddenly cut off and the E clouds were so much more active than usual that they almost ran continuously one into another. In at least one case the probability of a bright hydrogen eruption and a fade-out was confidently predicted on the ground that the near-in scattering was particularly active. But it is only a probability and not a certainty.

I suppose it is of some commercial and practical value to know about a partially or wholly scattered signal which is quite often made use of in actual commercial traffic. In such circumstances the scattered signal often arrives in a different direction from the true great-circle path, or it may be spread over a fairly wide angle. At such times a beam aerial directed along the true great-circle path may be of little use and better signals may be obtained on an omni-aerial, if direct reception by multiple reflections along the great-circle path is impossible and the only signals received are due to scattering. It may be of considerable value to know when such conditions occur, so as to be able to choose a suitable aerial for reception of the scattered signals. A knowledge of scattering may help us to know when a M.U.S.A. system would be profitable or not, and there are other services, such as facsimile and telephone transmission, in which it is necessary to know whether the mutilation produced by scattering is serious or not. In the latter part of his communication, Mr. Smale has quite effectively answered his own questions.

DISCUSSION ON "A NOTE ON SELF-INDUCTION"*

Mr. W. F. Dunton (*communicated*): The author says that my formula† for the force on the base b of a rectangular circuit of height h does not allow for the force exerted by the side opposite the base; and he mentions that the force between these parallel sides is

$$2I^2[\sqrt{(b^2/h^2+1)}-1] \quad . \quad . \quad . \quad . \quad (A)$$

My formula was, however, stated to be for the cases in which the side opposite the base is absent, which cases frequently have to be dealt with by designers of circuit-breakers. The same article gave expression (A) for the extra force exerted on the base when the opposite side is present. So far as I am aware, this convenient and accurate expression was there given for the first time.

The author is also under a misapprehension in suggesting that I do not distinguish between the radius r of a cylindrical conductor and the geometric mean distance $re^{-\frac{1}{4}}$. My article concludes with a proof that the geometric mean distance has this value; and the geometric mean distance was there used in obtaining formula (10*a*), with the remark that the formula was therefore preferable to my earlier one. In a subsequent article,† to which I drew Prof. O'Rahilly's attention when his book was published in 1938, I showed that there was room for improvement even in formula (10*a*).

* Paper by Prof. A. O'Rahilly (see page 179).

† *Journal of Scientific Instruments*, 1927, **4**, p. 440.

Prof. A. O'Rahilly (*in reply*): I am sorry if I misrepresented Mr. Dunton. It appears that in his formula (9*b*) in the *Journal of Scientific Instruments* he was deliberately neglecting the force due to the cross-piece. He also says he corrected on the next page his confusion between the radius of the wire and the geometrical mean distance, though I cannot discover the formula $\delta = re^{-\frac{1}{4}}$ in his paper. The *Electrician* for 1930 is not accessible to me.

Prof. W. V. Lyon of the Massachusetts Institute of Technology has drawn my attention to two slips in equations (10) and (12), which are re-statements of the correct equation (9).

Equation (10), first term: For "-1" read "$-(1+p)$."
Equation (12), last term: For "-1" read "-2."

† *Electrician*, 1930, **105**, p. 681.

HARMONIC POWER CONSUMPTION OF POLYPHASE RECTIFIER SYSTEMS*

By H. RISSIK.†

(*Paper first received 23rd October, and in revised form 11th December,* 1939.)

SUMMARY

The aims of the present paper are (1) to establish the general harmonic law of polyphase rectification, (2) to evaluate the distortion factor of the primary currents in a universal form, and (3) to derive a general expression for the correction factor which takes into account the effect of finite commutation on the shape of the primary current wave. In considering these aims it is to be remembered that—

(1) The existence of such a harmonic law has been known for some time, although its basis has hitherto remained obscure.

(2) The distortion factor has so far been evaluated only in specific cases and without any attempt at generalization.

(3) The possibility of being able to derive a general expression for the primary-current correction factor has hitherto not been suspected.

TABLE OF CONTENTS

(1) INTRODUCTION

The most important aspect of polyphase rectifying apparatus, considered as an a.c. load, is its harmonic loading of the supply system: for the fact that the rectification process is bound up with the consumption of wattless, non-reactive power—harmonic power, in short—is fundamental to a proper understanding of rectification phenomena. This fact, one that is characteristic not merely of rectifier circuits but of all a.c. circuits containing impedances which are functions of time,‡ leads at once to a unique relation between the input and output sides of any rectifying apparatus comprising a supply transformer and a polyphase rectifier system, viz. the relation between the occurrence of particular harmonics in the d.c. terminal voltage on the one hand, and in the transformer primary currents on the other hand. It should be emphasized here that the phenomenon of harmonic generation is inherent in the rectification process and that its origination in no way depends upon the type and design of the rectifier or its associated transformer.

(2) LIST OF SYMBOLS

p = number of rectifier phases.
n = order of a current or voltage harmonic.
m = any integer.
u = angle of overlap.
v_d = instantaneous value of rectifier output voltage.
V_d = mean value of rectifier output voltage.
V_n = r.m.s. value of the nth output voltage harmonic.
e = instantaneous value of primary phase voltage.
E = r.m.s. value of primary phase voltage.
i_d = instantaneous value of rectifier output current.
I_d = mean value of rectifier output current.
i = instantaneous value of primary current.
I = r.m.s. value of primary current.
i_n = instantaneous value of the nth primary current harmonic.
I_n = r.m.s. value of the nth primary current harmonic.
I_1 = r.m.s. value of the fundamental component of the primary current.
I' = r.m.s. value of the total harmonic content of the primary current

$$= \sqrt{(I^2 - I_1^2)} = \sqrt{\left[\frac{1}{2\pi}\int_0^{2\pi}\Sigma i_n^2 \,.\, d\theta\right]}$$

ϕ = phase angle between i_1 and e.
I_p = active component of $I_1 = I_1 \cos\phi$.
I_r = reactive component of $I_1 = I_1 \sin\phi$.
P_d = mean value of rectifier power output $= V_d I_d$.
P = active power input to transformer primary $= 3EI_p$.
P_R = reactive power input to transformer primary $= 3EI_r$.
P_H = harmonic power input to transformer primary $= 3EI'$.
P_A = apparent power input to transformer primary $= 3EI$.
μ = distortion factor of the primary current $= I_1/I$.
$\cos\phi$ = displacement factor of the primary current $= I_p/I_1$.
λ = power factor of the primary current $= I_p/I$.
α_n = voltage harmonic factor $= V_n/V_d$.
β_n = current harmonic factor $= I_n/I_1$.

(3) THE HARMONIC LAW OF POLYPHASE RECTIFICATION

In the ideal case of a rectifier installation devoid of transformer or other circuit reactance, as well as of all resistance, the instantaneous d.c. power output of the rectifier system must of necessity be equal to the instantaneous a.c. power input to the primary winding of the rectifier transformer. Assuming a symmetrical three-phase supply system, so that the primary phase voltages

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

† International Standard Electric Corporation.

‡ Cf. H. Rissik: "The Influence of Mercury-Arc Rectifiers on the Power Factor of the A.C. Supply System," *Journal I.E.E.*, 1933, **72**, p. 435.

e_R, e_Y and e_B all have the same r.m.s. value E, and denoting the corresponding primary currents by i_R, i_Y and i_B, we then obtain the fundamental power relation

$$v_d i_d = e_R i_R + e_Y i_Y + e_B i_B \quad . \quad . \quad . \quad (1)$$

where v_d and i_d are the instantaneous output voltage and current. It is usual to assume that the rectifier load is infinitely inductive, so that the several rectifier phase currents have a rectangular wave-form which is symmetrical about the maximum phase-voltage ordinate. Under these circumstances the primary current wave can contain only sine terms, each harmonic being of the form $i_n = \sqrt{2}I_n \sin n\theta$, where I_n is the r.m.s. value and n the order of the harmonic; whilst the output voltage wave can contain only cosine harmonics, of the form $v_n = \sqrt{2}V_n \cos n\theta$ between the limits $\theta = -(\pi/p)$ and $\theta = +(\pi/p)$, corresponding to the current-conducting period of each rectifier phase $(2\pi/p)$. We thus obtain the following further relations:—

$$\begin{aligned} v_d &= V_d + \sqrt{2}\Sigma V_n \cos n\theta. & i_d &= I_d. \\ e_R &= \sqrt{2}E \sin\theta. & i_R &= \sqrt{2}\Sigma I_n \sin n\theta. \\ e_Y &= \sqrt{2}E \sin(\theta + 2\pi/3). & i_Y &= \sqrt{2}\Sigma I_n \sin n(\theta + 2\pi/3). \\ e_B &= \sqrt{2}E \sin(\theta + 4\pi/3). & i_B &= \sqrt{2}\Sigma I_n \sin n(\theta + 4\pi/3). \end{aligned}$$

On substituting these several values in equation (1) one finally obtains, after some rearrangement of terms and trigonometrical reduction, the following general power equation:—

$$\begin{aligned} V_d I_d + \sqrt{2}I_d \Sigma V_n \cos n\theta \\ = 2E\Sigma I_n\bigg[\left(1 - \cos n\pi \cos\frac{n\pi}{3}\right) \sin n\theta \sin\theta \\ + \sqrt{3}\left(\cos n\pi \sin\frac{n\pi}{3}\right)\cos n\theta \cos\theta\bigg] \quad . \quad (2) \end{aligned}$$

Now in a symmetrical three-phase system the instantaneous sum of the currents is always zero, so that $i_R + i_Y + i_B = 0$. But in such a system the instantaneous sum of the harmonics i_n of order $n = 3, 6, 9$, etc., is not zero, and hence these triplen-current harmonics must themselves all be zero. Furthermore, the only symmetrical p-phase rectifier systems which can be supplied from a three-phase a.c. system are those having values of p which are multiples of 3. If $n = mp$, where m is any integer, then, since p is triplen, n must be triplen also. Also, as is well known in rectifier theory, the several voltage harmonics v_n are zero for all values of n other than $n = mp$.* Thus only certain triplen harmonics can occur in the output voltage; whereas it is precisely these triplen harmonics which are absent from the primary current. This fundamental harmonic relationship is a unique characteristic of polyphase rectification. To obtain a quantitative expression of this relationship it is necessary to evaluate equation (2). The two bracketed expressions on the right-hand side of this equation become zero for all values of n that are multiples of 3. For all non-triplen values of n, on the other hand, the first expression has the value 3/2, whilst the second expression has the value $\pm\frac{1}{2}\sqrt{3}$ depending on whether $n = (3m \pm 1)$, where m is any integer. So that, on developing the sine and cosine products in the usual manner by putting

$$\sin n\theta \sin\theta = \tfrac{1}{2}\big[\cos(n-1)\theta - \cos(n+1)\theta\big]$$

and $$\cos n\theta \cos\theta = \tfrac{1}{2}\big[\cos(n-1)\theta + \cos(n+1)\theta\big]$$

equation (2) finally takes the basic form

$$\begin{aligned} &V_d I_d + \sqrt{2}V_3 I_d \cos 3\theta + \sqrt{2}V_6 I_d \cos 6\theta + \ldots \\ &= 3EI_1 + 3E(I_2 - I_4)\cos 3\theta + 3E(I_5 - I_7)\cos 6\theta + \ldots (3) \end{aligned}$$

Inspection of this equation at once leads to two subsidiary relations of fundamental importance to rectifier theory, namely the active power relation

$$V_d I_d = 3EI_1 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and the harmonic power relation

$$\sqrt{2}V_n I_d = 3E(I_{n-1} - I_{n+1}) \quad . \quad . \quad . \quad (5)$$

Equation (4) indicates that the d.c. power output, $P_d = V_d I_d$, is equal to the true a.c. power input, $P = 3EI_1$, i.e. the power carried by the fundamental component of the primary current—a relation which is evident from energy considerations alone. Equation (5) expresses the fundamental "harmonic law" of polyphase rectification, which may be stated as follows:—

Every harmonic occurring in the d.c. terminal voltage of a polyphase rectifier system is inevitably associated with two harmonics, of the next lower and next higher order, in the alternating current drawn by the rectifier transformer from the three-phase a.c. supply.

In other words, the nth voltage harmonic on the d.c. side is always associated with the $(n-1)$th and the $(n+1)$th primary-current harmonics.

On putting $\alpha_n = V_n/V_d$, the voltage harmonic ratio, and $\beta_n = I_n/I_1$, the current harmonic ratio, division of equation (5) by equation (4) gives

$$\sqrt{2}\alpha_n = \beta_{n-1} - \beta_{n+1} \quad . \quad . \quad . \quad (6)$$

which is the quantitative expression, in its simplest form, of the harmonic law implicit in (5). Furthermore, as is well known in rectifier theory,* the voltage harmonics are defined by $V_n = \sqrt{2}V_d/(n^2 - 1)$, so that $\alpha = \sqrt{2}/(n^2 - 1)$. Hence equation (6) becomes

$$\beta_{n-1} - \beta_{n+1} = \frac{2}{n^2 - 1} = \frac{1}{n-1} - \frac{1}{n+1}$$

a relation which is only satisfied by the condition that $\beta_n = 1/n$, i.e. that

$$I_n = \frac{1}{n} \cdot I_1 \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The harmonic law of polyphase rectification thus leads to the important conclusion that the r.m.s. values of the primary-current harmonics are inversely proportional to their harmonic frequency and are independent of the number of rectifier phases. This relation stands in marked contrast to the corresponding relation for the rectifier phase currents. In that case, as has been shown previously,†

* Cf. H. RISSIK: "Harmonic Voltage Generation in Polyphase Rectifier Circuits," *Electrician*, 1939, **123**, p. 146.

* Cf. H. RISSIK: *Loc. cit.*

† Cf. H. RISSIK: "Harmonic Current Generation in Polyphase Rectifier Circuits," *Electrician*, 1940, **124**, p. 37.

$$I_n = \frac{\sqrt{2}}{n\pi} \sin \frac{n\pi}{p} \cdot I_d$$

so that

$$I_n = \frac{1}{n} \cdot I_1 \left[\frac{\sin (n\pi/p)}{\sin (\pi/p)} \right] \quad . \quad . \quad . \quad (8)$$

In interpretating equation (6) it is to be remembered that $n = mp$, where p is the number of rectifier phases and m is any integer, and that in practice p can only have values which are multiples of 3. The harmonic law of polyphase rectification thus leads to the numerical harmonic relationships of Table 1, in which α_n and β_n are expressed as percentages.

The importance of the conclusion expressed by (7) is that it at once enables one to evaluate the distortion factor of the primary current, that is to say the ratio of of the r.m.s. fundamental component I_1 to the r.m.s. resultant $I = \sqrt{(I_1^2 + I_2^2 + I_3^2 + \ldots)}$. If the r.m.s. value of all the harmonics be denoted by I', then, since $n = (mp \pm 1)$ on the primary side of the rectifier transformer, we have

$$I'^2 = \Sigma I_n^2 = I_1^2 \sum \left(\frac{1}{n^2}\right) = I_1^2 \sum_{m=1}^{m=\infty} \left(\frac{1}{mp \pm 1}\right)^2$$

$$= I_1^2 \sum_{m=1}^{m=\infty} \left[\left(\frac{1}{mp+1}\right)^2 + \left(\frac{1}{mp-1}\right)^2 \right]$$

$$= I_1^2 \sum_{m=1}^{m=\infty} \left[\frac{2(m^2p^2+1)}{(m^2p^2-1)^2} \right]$$

Making use of the infinite series

$$\pi^2 \operatorname{cosec}^2 (\pi\theta) = \frac{1}{\theta^2} + 2 \sum_{m=1}^{m=\infty} \left[\frac{m^2 + \theta^2}{(m^2 - \theta^2)^2} \right]$$

one thus obtains

$$I'^2 = I_1^2 \left(\frac{\pi^2}{p^2} \operatorname{cosec}^2 \frac{\pi}{p} - 1 \right)$$

so that

$$I^2 = I_1^2 + I'^2 = \frac{\pi^2}{p^2} \operatorname{cosec}^2 \frac{\pi}{p} \cdot I_1^2$$

The distortion factor is then simply

$$\mu = \frac{I_1}{I} = \frac{p}{\pi} \sin \frac{\pi}{p} \quad . \quad . \quad . \quad . \quad (9)$$

a result which is well known in rectifier theory.

Table 1

THE HARMONIC FREQUENCY SPECTRUM

Number of rectifier phases		$p = 3$		$p = 6$		$p = 9$		$p = 12$	
% harmonic		α_n	β_n	α_n	β_n	α_n	β_n	α_n	β_n
Order of the harmonic, n	1*	—	100·0	—	100·0	—	100·0	—	100·0
	2	—	50·0	—	—	—	—	—	—
	3	17·71	—	—	—	—	—	—	—
	4	—	25·0	—	—	—	—	—	—
	5	—	20·0	—	20·0	—	—	—	—
	6	4·04	—	4·04	—	—	—	—	—
	7	—	14·3	—	14·3	—	—	—	—
	8	—	12·5	—	—	—	12·5	—	—
	9	1·77	—	—	—	1·77	—	—	—
	10	—	10·0	—	—	—	10·0	—	—
	11	—	9·1	—	9·1	—	—	—	9·1
	12	0·99	—	0·99	—	—	—	0·99	—
	13	—	7·7	—	7·7	—	—	—	7·7
	14	—	7·1	—	—	—	—	—	—
	15	0·63	—	—	—	—	—	—	—
	16	—	6·2	—	—	—	—	—	—
	17	—	5·9	—	5·9	—	5·9	—	—
	18	0·44	—	0·44	—	0·44	—	—	—
	19	—	5·3	—	5·3	—	5·3	—	—
	20	—	5·0	—	—	—	—	—	—
	21	0·32	—	—	—	—	—	—	—
	22	—	4·5	—	—	—	—	—	—
	23	—	4·3	—	4·3	—	—	—	4·3
	24	0·25	—	0·25	—	—	—	0·25	—
	25	—	4·0	—	4·0	—	—	—	4·0

* Fundamental component.

(4) HARMONIC GENERATION ON THE PRIMARY SIDE OF RECTIFIER TRANSFORMERS

So far the r.m.s. value I of the primary current has been evaluated indirectly by summation of the fundamental and harmonic components. Its direct evaluation from a consideration of the primary-current wave form is of importance, however, in that it demonstrates the correctness of the analysis leading up to the basic power relation expressed by equation (3), from which the harmonic law expressed by equation (6) automatically follows. The condition that the number of phases in a symmetrical polyphase rectifier system fed from a three-phase a.c. supply must be a multiple of 3 leads, in the first place, to symmetry of the primary current wave form about the maximum phase-voltage ordinate. In the second place, a little consideration will show that it means also that each primary phase must carry the equivalent of two or more rectifier phase currents (i.e. transformer secondary currents). As the result, the primary winding of the rectifier transformer carries a symmetrical alternating current having a stepped wave form, as indicated in Fig. 1 which shows the positive half-waves only. The wave form of diagram (a) occurs in the case of those transformer connections which result in phase coincidence between the primary and secondary phase voltages. The alternative wave form of diagram (b) occurs in the case of those connections giving rise to a phase difference of π/p between these voltages. However, both wave forms contain the same harmonics, and have the same r.m.s. value and the same distortion factor. They are distinguished only by specific differences in phase between the fundamental component and the several harmonics.*

In either case, and as will appear subsequently, the height of the middle step H_1 is equal to the peak value of the equivalent sine wave, i.e. the sinusoid having the same r.m.s. value I as the stepped wave. The width of the several steps is $2\pi/p$, the current-conducting period per rectifier phase, and they are symmetrically disposed with regard to the maximum phase-voltage ordinate. If $\theta = \omega t$ be reckoned from this axis, then the middle step H_1 extends from $-\pi/p$ to $+\pi/p$; and the subsequent pairs of steps H_k extend from $\theta = -(2k-1)\pi/p$ to $\theta = -(2k-3)\pi/p$ and from $\theta = +(2k-3)\pi/p$ to $\theta = +(2k-1)\pi/p$. In the case of wave form (a) the last pair of steps H_l extend from $\theta = -\pi/2$ to $\theta = -(\pi/2 - 2\pi/p)$ and from $\theta = +(\pi/2 - 2\pi/p)$ to $\theta = +\pi/2$; so that $(2l-1)\pi/p = \pi/2$, or $l = \frac{1}{4}(p+2)$. In the case of wave form (b) the corresponding limits of H_l are $\theta = -(\pi/2 - \pi/p)$ and $\theta = -(\pi/2 - 3\pi/p)$, and $\theta = +(\pi/2 - 3\pi/p)$ and $\theta = +(\pi/2 - \pi/p)$; so that $(2l-1)\pi/p = (\pi/2 - \pi/p)$, or $l = \frac{1}{4}p$. In general, therefore,

$$l = \tfrac{1}{4}(p + 1 \pm 1) \quad . \quad . \quad . \quad . \quad (10)$$

Furthermore, the height of each symmetrically placed pair of steps is clearly given by $H_k = \cos(k-1)2\pi/p$, where $k = 1, 2, 3, \ldots, l$.

The primary-current wave can be represented by the Fourier series $i = \Sigma A_n \cos n\theta$, in which the coefficient of the nth harmonic is given by

$$A_n = \frac{2}{\pi}\left[\int_{-\pi/p}^{+\pi/p} H_1 \cos n\theta d\theta + 2\int_{\pi/p}^{3\pi/p} H_2 \cos n\theta d\theta + \ldots + 2\int_{(2k-3)\pi/p}^{(2k-1)\pi/p} H_k \cos n\theta + \ldots + 2\int_{(2l-3)\pi/p}^{(2l-1)\pi/p} H_l \cos n\theta d\theta\right]$$

Bearing in mind that $n = (mp \pm 1)$, where m is any integer, and substituting the value of H_k given above, one finds

$$\begin{aligned} A_n &= \frac{2H_1}{\pi}\left[\int_{-\pi/p}^{+\pi/p} \cos(mp \pm 1)\theta \,.\, d\theta + 2\sum_{k=2}^{k=l} \cos(k-1)\frac{2\pi}{p}\int_{-\pi/p}^{+\pi/p} \cos(mp \pm 1)\left\{\theta + (k-1)\frac{2\pi}{p}\right\} d\theta\right] \\ &= \frac{2H_1}{\pi}\left[\frac{2\sin(mp \pm 1)\frac{\pi}{p}}{(mp \pm 1)} + \frac{4\sin(mp \pm 1)\frac{\pi}{p}}{(mp \pm 1)} \cdot \sum_{k=2}^{k=l} \cos(k-1)\frac{2\pi}{p}\cos(k-1)(mp \pm 1)\frac{2\pi}{p}\right] \\ &= \pm\frac{4H_1}{n\pi}\sin\frac{\pi}{p} \cdot \left[1 + 2\sum_{k=2}^{k=l}\cos^2(k-1)\frac{2\pi}{p}\right] \\ &= \pm\frac{4H_1}{n\pi}\sin\frac{\pi}{p} \cdot \left[\frac{p}{4}\right] \end{aligned}$$

This final result is obtained by summation of the (cosine)^2 series and substitution of the value of l given by (10). The r.m.s. value of the nth harmonic is thus

$$I_n = \frac{1}{\sqrt{2}}A_n = \frac{p}{n\pi\sqrt{2}}\sin\frac{\pi}{p} \cdot H_1 \quad . \quad . \quad (11)$$

On putting $n = 1$, one finds for the r.m.s. fundamental component

$$I_1 = \frac{p}{\pi\sqrt{2}}\sin\frac{\pi}{p} \cdot H_1 \quad . \quad . \quad . \quad . \quad (12)$$

Substituting H_1 from (12) in (11) then gives $I_n = I_1/n$, which is the universal harmonic relation of equation (7). The validity of the foregoing analysis, based on the stepped wave forms of Fig. 1, is thereby established.

The r.m.s. value of the primary current is given by

$$\begin{aligned} I^2 &= \frac{1}{\pi}\left(H_1^2 \cdot \frac{2\pi}{p} + 2H_2^2 \cdot \frac{2\pi}{p} + \ldots 2H_k^2 \cdot \frac{2\pi}{p} + \ldots + 2H_l \cdot \frac{2\pi}{p}\right) \\ &= \frac{2H_1^2}{p} \cdot \left[1 + 2\sum_{k=2}^{k=l}\cos^2(k-1)\frac{2\pi}{p}\right] \end{aligned}$$

* Cf. H. Jungmichl: "Harmonics in the Primary Currents of Rectifier Installations," *Elektrotechnische Zeitschrift*, 1931, **52**, p. 171.

$$= \frac{2H_1^2}{p} \cdot \left[\frac{p}{4}\right]$$

$$= \frac{H_1^2}{2}$$

and is thus

$$I = \frac{1}{\sqrt{2}} H_1 = \frac{\pi}{p} \operatorname{cosec} \frac{\pi}{p} \cdot I_1 \quad . \quad . \quad . \quad (13)$$

The height of the middle step H_1 is, therefore, the peak value of a sine wave whose r.m.s. value I is that of the actual stepped wave. Furthermore, equation (13) at

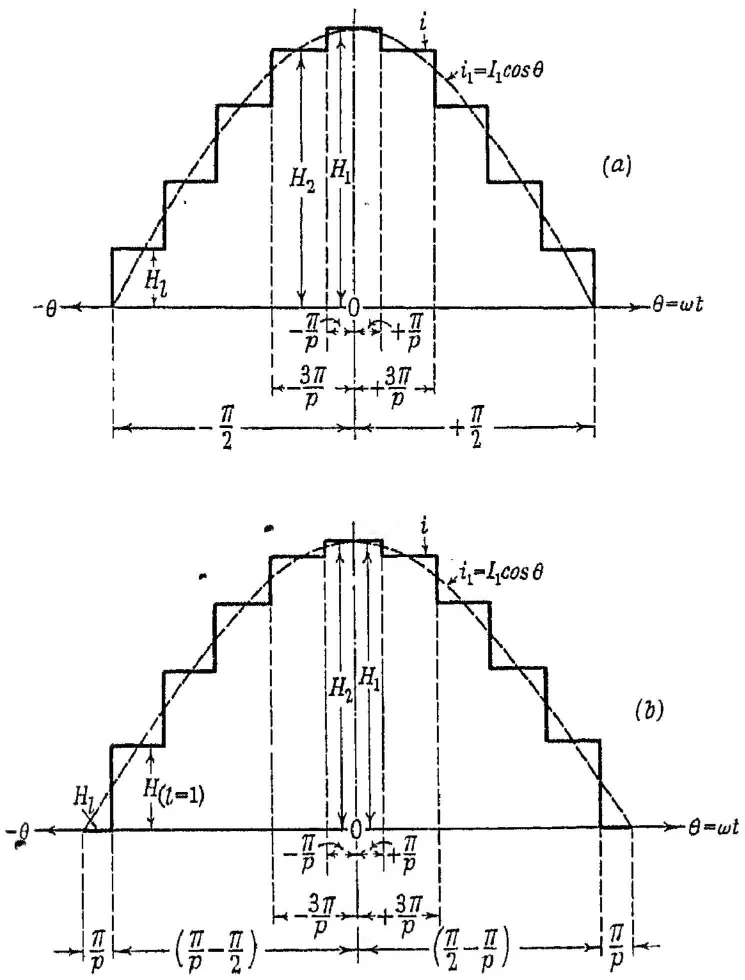


Fig. 1

once gives for the distortion factor of the primary current

$$\mu = \frac{I_1}{I} = \frac{p}{\pi} \sin \frac{\pi}{p} \quad . \quad . \quad . \quad . \quad (14)$$

which is the same result as (9), as is to be expected.

(5) THE EFFECTS OF TRANSFORMER REACTANCE

In the case of an actual rectifier system the effect of transformer reactance is to introduce a finite interval of phase commutation—represented by the so-called angle of overlap u—which results in a modification of the ideal stepped wave form shown in Fig. 1. . In consequence of this modification the individual harmonics as well as the fundamental component of the primary current are altered both in magnitude and phase, resulting in a change in the r.m.s. value of the resultant current together with a displacement of the fundamental component from its position of phase coincidence with the primary phase voltage. Both changes are a function of the overlap angle u, the former producing a change in the harmonic power consumption and the latter giving rise to a consumption of reactive power. That is to say, in addition to the wattless power expended in harmonic generation, a further proportion of the total or apparent power drawn from the a.c. supply is utilized in overcoming electromagnetic inertia, represented mainly by the inevitable inductance of the transformer windings.

The conception of reactive power of course arose originally in connection with sinusoidally alternating currents and voltages, where the magnitude of the reactive power is given by the r.m.s. product of the voltage and the component of the current in phase quadrature with that voltage. In the general case where the current is not sinusoidal, but its several components —fundamental and harmonics—are regarded as being such, and the generating voltage remains sinusoidal, the reactive power is given by the r.m.s. product of the voltage and the quadrature component of the funda-

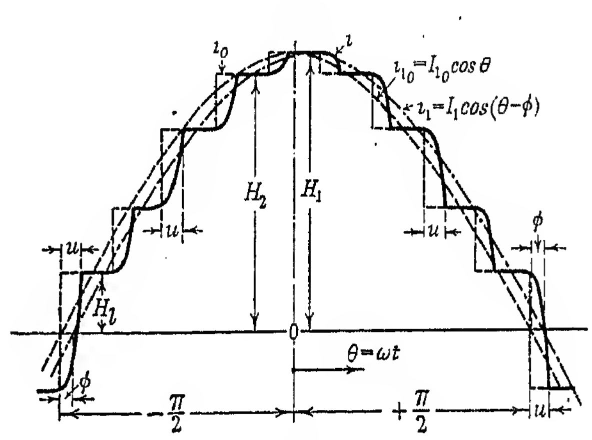


Fig. 2

mental sinusoidal current. Thus if I_1 denote, as before, the r.m.s. value of the fundamental component of the primary current and if ϕ be its phase angle with respect to the primary phase voltage, then the power or in-phase component of the fundamental is $I_p = I_1 \cos \phi$, whilst the reactive or quadrature component is $I_r = I_1 \sin \phi$. Hence the active power consumption of the rectifier system is $P = 3EI_p = 3EI_1 \cos \phi$, whilst the corresponding reactive power consumption is then $P_R = 3EI_r = 3EI_1 \sin \phi$. The harmonic power consumption remains, of course, $P_H = 3EI' = 3E\sqrt{(I^2 - I_1^2)} = P_A\sqrt{(1 - \mu^2)}$, where $P_A = 3EI$ is the total or apparent power consumption. The power factor of the primary current is thus $\lambda = P/P_A = \mu \cos \phi$; the induction factor is $P_R/P_A = \mu \sin \phi$; whilst the harmonic factor is $P_H/P_A = \sqrt{(1 - \mu^2)}$.

The effect of transformer reactance, then, is to modify the primary current from the ideal wave form shown in Fig. 1 to that of Fig. 2.* Here the individual steps no longer have vertical sides but are flanked by the overlapping sections of the individual rectifier phase-current waves. A little consideration will show that the rising sections are represented by the function $(H_k - H_{k+1}) \cdot w\left\{\theta + (2k - 1)\pi/p\right\}$, whilst the falling sections are similarly represented by the function $(H_k - H_{k+1}) \cdot \left[1 - w\left\{\theta - (2k - 1)\pi/p\right\}\right]$, where $w(\theta)$

* Only the wave form of diagram (a) has been repeated here. The subsequent analysis, however, applies equally to the alternative wave form of diagram (b)

$= (1 - \cos\theta)/(1 - \cos u)$ is the well-known function determining the growth of the rectifier phase currents during the intervals of overlap.* The primary-current wave is in this case represented by the Fourier series $i = \Sigma A_n \cos n\theta + \Sigma B_n \sin n\theta$, the coefficients A_n and B_n as usual being defined by

$$A_n = \frac{2}{\pi}\int_0^\pi i \cos n\theta \,.\, d\theta$$

$$B_n = \frac{2}{\pi}\int_0^\pi i \sin n\theta \,.\, d\theta$$

By analysing the wave form of Fig. 2 along the lines established for Fig. 1, a general expression for the primary current i can be obtained in terms of symmetrically disposed pairs of steps. Integration of the products $i \cos\theta$ and $i \sin\theta$ between the limits $\theta = -(2l - 1)\pi/p$ and $+(2l - 1)\pi/p$, where l is given by equation (10), then gives for the first-order Fourier coefficients

$$A_1 = H_1\frac{p}{\pi}\sin\frac{\pi}{p}\cdot\left[\frac{1 - \cos 2u}{4(1 - \cos u)}\right]$$

and

$$B_1 = H_1\frac{p}{\pi}\sin\frac{\pi}{p}\cdot\left[\frac{2u - \sin 2u}{4(1 - \cos u)}\right]$$

Hence the active and reactive components of the primary current become

$$I_p = I_1\cos\phi = \frac{1}{\sqrt{2}}A_1 = I_{1_0}\left[\frac{1 - \cos 2u}{4(1 - \cos u)}\right] \quad (15a)$$

and $$I_r = I_1\sin\phi = \frac{1}{\sqrt{2}}B_1 = I_{1_0}\left[\frac{2u - \sin 2u}{4(1 - \cos u)}\right] \quad (15b)$$

where I_{1_0} is the r.m.s. value of the fundamental component in the ideal case when $u = 0$, as given by (12). The phase angle ϕ by which the fundamental primary current lags behind its corresponding phase voltage is thus given by

$$\tan\phi = \frac{2u - \sin 2u}{1 - \cos 2u} \quad . \quad . \quad . \quad . \quad (16)$$

which is the same relation as that obtained in the case of the rectifier phase currents.† That this must be so is evident from magnetic energy considerations alone, the reactive power loading on the secondary side of the rectifier transformer being transmitted without change to the primary side. The displacement factor of the primary current is thus

$$\cos\phi = \frac{1}{\sqrt{(1 - 2u\cot u + u^2\operatorname{cosec}^2 u)}} \quad . \quad (17)$$

As is well known in rectifier theory, (16) or (17) gives as a close approximation $\phi = \frac{2}{3}u$.

The change in harmonic content brought about by the change in wave form due to rectifier phase-current overlap is also reflected in the r.m.s. value I. Integration of i^2 between the limits defined above gives for the r.m.s. value of the primary current

$$I^2 = \frac{2}{p}\left(H_1^2 + 2\sum_{k=2}^{k=l} H_k^2\right) - 2\sum_{k=1}^{k=l}(H_k - H_{k+1})^2\cdot\frac{1}{\pi}\int_0^u\left[w(\theta) - w^2(\theta)\right]d\theta$$

with $H_{k+1} = 0$ when $k = l$ (Fig. 2). The first term of the above expression is

$$\begin{aligned}\frac{2H_1^2}{p}\left[1 + 2\sum_{k=2}^{k=l}\left(\frac{H_k}{H_1}\right)^2\right] &= \frac{2H_1^2}{p}\left[1 + 2\sum_{k=2}^{k=l}\cos^2(k-1)\frac{2\pi}{p}\right] \\ &= \frac{2H_1^2}{p}\left[\frac{p}{4}\right] \\ &= \frac{H_1^2}{2}\end{aligned}$$

and corresponds to I^2 in the ideal case where $u = 0$, as may be seen by reference to the derivation of equation (13). The integral in the second term is the current overlap function $\psi(u)$, well known in rectifier theory. The above expression for I^2 thus leads to

$$\begin{aligned}I &= \frac{H_1}{\sqrt{2}}\cdot\sqrt{\left[1 - \kappa\,.\,\psi(u)\right]} \\ &= I_0\sqrt{\left[1 - \kappa\,.\,\psi(u)\right]} \quad . \quad . \quad . \quad . \quad (18)\end{aligned}$$

where $I_0 = H_1/\sqrt{2}$ is the value of I in the ideal case where $u = 0$, and the factor κ is a function of p alone, viz.:—

$$\begin{aligned}\kappa &= 4\sum_{k=1}^{k=l}\left(\frac{H_k - H_{k+1}}{H_1}\right)^2, \text{ with } H_{k+1} = 0 \text{ when } k = l, \\ &= 8\sin^2\frac{\pi}{p}\sum_{k=1}^{k=(l-1)}\left[1 - \cos(2k-1)\frac{2\pi}{p}\right] + 4\cos^2(l-1)\frac{2\pi}{p} \\ &= 8\sin^2\frac{\pi}{p}\cdot\left[\frac{p}{4}\right] \\ &= p\left(1 - \cos\frac{2\pi}{p}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)\end{aligned}$$

The effect of transformer reactance is therefore to reduce the r.m.s. primary current by the factor

$$\sqrt{\left[1 - p(1 - \cos 2\pi/p)\,.\,\psi(u)\right]}$$

as compared with the well-known reduction factor $\sqrt{[1 - p\,.\,\psi(u)]}$ in the case of the secondary (or rectifier phase) current. Table 2 gives values of the factor κ for several values of p.*

* See H. RISSIK: "Mercury-Arc Current Convertors," pp. 26 *et seq.* (Sir Isaac Pitman and Sons, Ltd., 2nd. edn., 1940).

† Cf. H. RISSIK: "Harmonic Current Generation in Polyphase Rectifier Circuits," *Electrician*, 1940, **124**, p. 38, eqn. (10).

* O. K. MARTI and W. WINOGRAD in their book "Mercury-Arc Power Rectifiers" (McGraw-Hill, 1930) have analysed the primary-current wave form in the specific case of 12-phase rectification, arriving at the numerical value $\kappa = 1 \cdot 61$. No attempt has been made so far, however, to obtain a general expression for κ which can be universally applied, viz. equation (19) above.

Equations (15*a*) and (15*b*) give for the r.m.s. value of the fundamental component

$$I_1 = \sqrt{(I_p^2 + I_r^2)}$$
$$= I_{1_0} \cdot \frac{\sqrt{[u^2 - 2u \sin u \cos u + \sin^2 u]}}{2(1 - \cos u)} \quad . \quad (20)$$

which is the same relation between the actual and ideal values of the fundamental component as that obtaining in the case of the rectifier phase currents.* It is to be noted, however, that in the case of the primary currents not only is the reduction factor of the fundamental component I_1 independent of p, but those of its sine and

Table 2

p	2	3	4	6	12
κ	4	4·5	4	3	1·61

cosine components (viz. I_r and I_p) are also independent of p and are functions of u alone, which is not the case for the rectifier phase currents. It can be shown that this applies equally to the several primary-current harmonics. Integration of the products $i \cos n\theta \,.\, d\theta$ and $i \sin n\theta \,.\, d\theta$ between the same limits as before gives for the nth-order Fourier coefficients

$$A_n = H_1 \cdot \frac{p}{n\pi} \sin \frac{\pi}{p} \left[\frac{\cos nu \cos u + n \sin nu \sin u - 1}{(n^2 - 1)(1 - \cos u)}\right] \quad (21a)$$

and

$$B_n = H_1 \cdot \frac{p}{n\pi} \sin \frac{\pi}{p} \left[\frac{n \cos nu \sin u - \sin nu \cos u}{(n^2 - 1)(1 - \cos u)}\right] \quad (21b)$$

from which the r.m.s. value of the nth harmonic is found to be

$$I_n = \frac{I_{1_0}}{n} \cdot \frac{\sqrt{[(\cos nu - \cos u)^2 + (\sin nu - n \sin u)^2]}}{(n^2 - 1)(1 - \cos u)} \quad (22)$$

where, as before, I_{1_0} is the r.m.s. value of the fundamental in the ideal case where $u = 0$. On comparing (22) with (20) it will be seen that, although the fundamental harmonic law still holds in the case where transformer reactance is taken into account—that is to say $n = (mp \pm 1)$, where m is any integer—the corollary relation expressed by (7) only applies in the ideal case. Due to the change in primary-current wave form brought about by the overlapping of the rectifier phase currents during the commutation process, the r.m.s. values of the primary-current harmonics no longer remain inversely

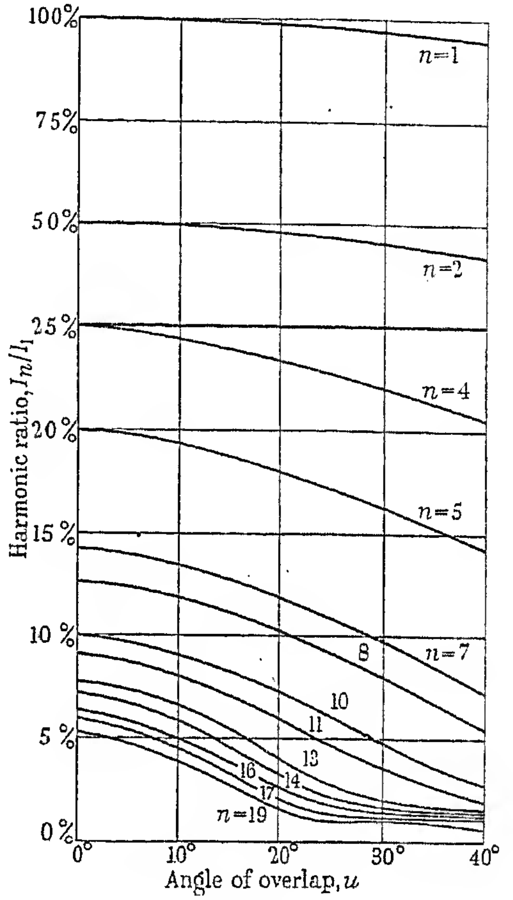


Fig. 3

proportional to the harmonic frequency, but are further reduced by the factor

$$\frac{2}{n^2 - 1} \cdot \sqrt{\left[\frac{(\cos nu - \cos u)^2 + (\sin nu - n \sin u)^2}{u^2 - 2u \sin u \cos u + \sin^2 u}\right]}$$

This is clearly shown by Fig. 3, which indicates the variation in r.m.s. value of the several primary-current harmonics given in Table 1 as a function of the angle of overlap u.

* Cf. H. Rissik: *Electrician*, 1940, **124**, p. 38, eqn. (8).

REPORT OF THE COUNCIL FOR THE YEAR 1939-1940, PRESENTED AT THE ANNUAL GENERAL MEETING OF THE 9TH MAY, 1940

CONTENTS

CONTENTS—*continued.*

REPORT

At this, the Sixty-Eighth Annual General Meeting of The Institution, the Council present to the members their Report for the year 1939–40. In submitting these details of The Institution's activities during the period from the 1st April, 1939, to the 31st March, 1940, the Council desire to express their cordial thanks for the full measure of support which they have received from so many of the members, who by serving on Committees and in other ways have rendered valuable assistance in placing their knowledge and experience at the disposal of The Institution.

The period covered by this Report has been a particularly difficult one for members as a result of the outbreak of hostilities. Many members of The Institution have found their energies called upon to a greater extent than ever to assist in the national effort by ensuring that efficiency and technical improvements are kept well abreast with the greatly increased demand for the special services required from the electrical engineering industry under existing conditions. At the same time a large number of members are contributing to the common cause by serving in Units of the Forces where their technical training will be of the greatest use.

In the general adaptation that has been necessary to meet the conditions with which the world is faced to-day the Council have endeavoured, in directing the policy of The Institution, to ensure that it shall play a part commensurate with its power and prestige.

(1) THE SECRETARY

Mr. P. F. Rowell's intention to resign the Secretaryship of The Institution was referred to in the last Annual Report, and as the first step to finding a successor an advertisement was inserted in the technical and daily Press and was reproduced in "Institution Notes" in the *Journal*. The choice of the Council fell upon Mr. William Kenneth Brasher, B.A., Member, who took up his duties as Secretary on the 1st September, 1939.

Mr. Brasher, who at the time of his appointment was Engineer-in-Chief of Posts and Telegraphs, Palestine, was educated at Clifton College and at St. John's College, Cambridge. During the last war he held a commission in the Royal Engineers (Signals) and served in France.

After being employed for some time in the Design Department of the Marconi works at Chelmsford he was appointed assistant engineer in the Post Office Engineering Department of British Guiana, where he later became chief engineer. He was subsequently for 4 years Executive Engineer of Posts and Telegraphs, Iraq.

The Selection Committee had as its Chairman the President, Dr. A. P. M. Fleming. Appreciation of his especial services in this connection has been recorded in a Resolution passed by the Council at their meeting on 4th July, 1939.

(2) P. F. ROWELL TESTIMONIAL

It was felt that the occasion of Mr. P. F. Rowell's retirement from the Secretaryship, which he had held for 30 years (subsequent to service on the staff for 8 years) afforded a fitting opportunity to express appreciation of his work for The Institution. The Council thought that many members, especially those who had come into more personal contact with Mr. Rowell during his long years of service, would wish to join with them in subscribing to a testimonial, and that Mr. Rowell himself would appreciate the participation of a large number of members in such a testimonial more highly than its monetary value. For this reason it was suggested in the appeal circulated to members that the amount of each contribution should not exceed 2s. 6d. The testimonial reached the net total of £163 8s. 11d., of which a sum was set aside at Mr. Rowell's request for the purchase of a small collection of books, which he wished to have as a permanent souvenir. Members in Western Australia, instead of contributing to the testimonial direct, decided, as a mark of local sentiment, to contribute towards a separate gift, which took the form of a suitably inscribed cigar box made from rare Australian woods.

The Council had hoped to arrange for a formal presentation of the books, and of a cheque for the remainder of the testimonial, at the opening of the Session, when an opportunity would have been afforded to express personally to Mr. Rowell the high appreciation of his long years of service. Unfortunately this could not be arranged, and the following letter was accordingly addressed to him on behalf of the Council:—

P. F. Rowell, Esq. *7th December*, 1939

Dear Mr. Rowell,

The Council were very disappointed you could not be with them on the 16th November in the Council Room in which you so ably guided the proceedings of The Institution for so many years and which must recall many associations. You have given the greater part of your working life to The Institution and your presence will be sorely missed, not only in the Council Chamber, but at the Ordinary Meetings, Centres, Social Functions and Summer Meetings. You have seen great developments in the growth of The Institution during your 38 years' service.

The Institution is indebted to you in many respects, particularly do I refer to the negotiations in connection with our Royal Charter; the exemption of The Institution from income tax; the financial success of The Institution; the re-drafting of the Bye-laws; the development of the Centres, Sub-Centres and Sections, and the friendly liaison you created with our French colleagues. In this connection we were all delighted when your efforts were recognized in 1936 by the award of the Legion of Honour (Chevalier).

It is my very pleasant duty to present to you on behalf of all members of The Institution the enclosed cheque for £160 as a symbol of the regard with which we hold you and to wish you and yours many years of health and happiness in your well-earned retirement.

Yours sincerely,

JOHNSTONE WRIGHT,

President.

[It is with deep regret that the Council have learned, since this Report was drafted, of the death of Mr. Rowell at Weymouth on the 14th April, 1940. In recording this the Council deplore the very short duration of the well-earned period of leisure and relaxation enjoyed by Mr. Rowell after so many years of active work devoted to the service of The Institution.]

(3) MEMBERSHIP OF THE INSTITUTION

The following Table shows the net growth of membership for the last 10 years:—

Year (31st March)	*Membership*	*Increase*
1931	14 670	470
1932	14 884	214
1933	15 149	265
1934	15 619	470
1935	16 150	531
1936	16 788	638
1937	17 399	611
1938	18 252	853
1939	19 044	792
1940	19 872	828

The changes in the membership since the 1st April, 1939, are shown in Appendix A.

(4) HONORARY MEMBER

The Council have pleasure in recording that, as announced at the Ordinary Meeting on the 25th January, 1940, they have elected Mr. Roger Thomas Smith, B.Sc. (Past-President), to be an Honorary Member of The Institution.

(5) FARADAY MEDAL

The eighteenth award of the Faraday Medal has been made by the Council to Dr. Alexander Russell, M.A., D.Sc., LL.D., F.R.S. (Honorary Member; Past-President).

As Dr. W. D. Coolidge, to whom the seventeenth award of the Medal was made last year, was unable to come to this country the presentation was made on behalf of the Council by Mr. Gano Dunn, I.E.E. Local Honorary Secretary for the U.S.A., at the North-Eastern District Annual Convention of the American Institute of Electrical Engineers held at Springfield, Mass., on 4th May, 1939.

(6) HONOURS AND DISTINCTIONS CONFERRED ON MEMBERS

K.C.B.

Kennedy-Purvis, Charles Edward, Vice-Admiral, C.B., R.N. (Member).

K.C.I.E.

Pitkeathly, Sir James Scott, C.M.G., C.I.E., C.V.O., C.B.E., D.S.O. (Associate Member).

O.B.E.

Read, Alfred Howard, Lt.-Col., T.D., M.Eng. (Associate Member).

M.B.E.

Mersh, Charles Melmoth B. (Member).
Osborne, Charles (Associate Member).

D.S.O.

Daniel, Charles Saumarez, Captain, R.N. (Associate Member).

It is gratifying to be able to record the award to Sir George Lee, O.B.E., M.C. (Past-President), of the Medal of Honour for 1939 of the Institute of Radio Engineers (U.S.A.), "for his accomplishments in promoting international radio services and in fostering advances in the art and science of radio communication."

The award to Mr. Gano Dunn (Local Honorary Secretary for the U.S.A.) of the Hoover Medal for 1939 is also recorded with pleasure. The Medal is in the joint award of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. The award "signalizes great unselfish non-technical service by engineers to their fellowmen," not in lieu of but above and beyond the full measure of technical attainment, which is a primary but not the ultimate criterion. In making the award, reference was made to Mr. Dunn as "long honoured by his fellow engineers for professional achievements but having, beyond that, exemplified high civic purpose and a devotion to public service."

(7) DEATHS

It is with regret that the Council have to record the loss, during the year under review, of the following three members serving with His Majesty's Forces:—

Killed in Action.

Meredith, E. G. (Graduate), Sub-Lieut., R.N.R.

Killed on Active Service.

Taylor, G. S., B.A. (Graduate), Pilot Officer, R.A.F.
Warren, J. H. (Student), Flying Officer, R.A.F.

The Council also regret to have to record the deaths of the following 119 members of The Institution during the year:—

Honorary Members

Atkinson, Ll. B.
Crompton, Col. R. E. B., C.B., F.R.S.
Kennelly, Prof. A. E., D.Sc.

Members

Atchison, A. F. T., B.Sc.
Baldwin, O. H.
Bartholomew, S. C., M.B.E.
Benham, E. E.
Berry, H. H.
Blackmore, R.
Burkinshaw, H.
Chambers, Col. J. C., C.B.
Clements, F. W.
Collette, A. E. R.
Corns, S. W.
Cramp, Prof. W., D.Sc.
Davidson, A.
Donkin, H. J., M.B.E.
Evershed, S.
Fletcher, R. H., B.A.
Frisby, W.
Gregory, H. W.
Harrison-Watson, R. A.
Haslam, A. P.
Haworth, Dr. H. F., M.Sc., B.Eng.
Hesketh, T.
Holden, S. H.
Jackson, A. H., B.Sc.
Klitz, Major R. W.
Lea, F. M.
Lindop, V.
Little, C. W. G.
Long, F. M.
Lunn, J. R. P.
Maddock, G. M.
Migotti, L. W.
Nash, R. P.
Odam, J. H.
Ogilvie, A., O.B.E., B.Sc.
O'Meara, Lt.-Col. W. A. J., C.M.G., late R.E.
Robertson, A. B., jun., D.S.O.
Robson, R. E.
Simon, H. F.
Smith, J. C.
Smith, Sidney.
Stanton, A. L.
Wilkinson, H. W.

Associate Members

Bailey, A.
Baker, E. R., B.Sc.(Eng.).
Ballard, A. L.
Banks, A. E.
Barfield, E. P.
Barlow, F.
Bodkin, G. S. C.
Broster, R. A.
Clarke, A. V.
Cox, A. W.
Dale, S.
Davidson, H. S.
Davies, J. L.
Elliot, J.
Fairfield, T. J.
Fiander, C. M.
Finlay, G.
Fourniss, C. W.
Gobie, H.
Gupta, C. L., B.Sc.Tech.
Jenkin, P. O.
King, W. H.
Lowe, B.
Lund, G.
McPherson, A.
Margetts, J. M. A.
Mason, P. H.
Michael, E. F., B.Sc.
Midgley, T. S.
Miller, L.
Neale, H. A.
Pearson, T.
Plunkett, M. P.
Porteous, D. A. S.
Riley, G. E.
Rowland, W.
Rowles, H. P.
Shettle, W. C.
Vacy-Ash, W. M., O.B.E.
Wenger, Lt.-Col. T. L., M.C.
Westbrook, R. P., B.Sc.
Wright, A., B.Sc.
Yuille, P. W., B.Sc.

Companion

Boothman, J.

Associates

Coward, H. J. V.
Griffith, F. P., B.A.
Lewis, G.

Graduates

Bayliss, W. C.
Beattie, R. K., B.Sc.
Clements, D. E.
Easton, W. R.
Goodleff, J.
Hutt, E. J., B.Sc.(Eng.).
Jones, A. N., B.Sc.(Eng.).
Lamb, D. A.
Neville, A.
Overington, L. E.
Rangaswamengar, K. S., B.Sc.

Graduates—continued

Tandon, M. K., B.A.	Trencham, H. K.
Todd, D., B.Sc.Tech.	Wells, E. H., Ph.D., M.Sc.

Students

Cairnduff, W. P.	Logan, J.
Dawson, E. H.	May, F. R.
Fanthorpe, J. R.	Morgan, I. F.
Hazlehurst, C.	Tyson, G. M.
Lees-Spalding, J. P.	Venner, H.
Young, G. S.	

The Council have recorded above with profound regret the death of Colonel Rookes Evelyn Bell Crompton, C.B., F.R.S., the doyen of The Institution, who in addition to having twice been President was also an Honorary Member and a Faraday Medallist. It was felt that Colonel Crompton's many friends would wish to have an opportunity of paying tribute to one who held so unique a position in the engineering profession and had such varied interests, and with the approval of Colonel Crompton's relatives The Institution arranged a Memorial Service, which was held at the Church of St. Margaret, Westminster, on Thursday the 22nd February, 1940, and was extremely well attended.

A further serious loss to The Institution has resulted from the death of Mr. Llewelyn B. Atkinson, Past-President and Honorary Member, and the Council take this opportunity of paying tribute to the great work which throughout his active career he did for The Institution and for the industry as a whole. The year of his Presidency, 1920–21, was an outstanding one in the history of The Institution, as in August, 1921, the Royal Charter was granted. His election by the Council in 1933 as an Honorary Member was a well-merited distinction.

(8) INSTITUTION ACTIVITIES AND THE WAR

On the 13th September last, at the request of the President, an Emergency Committee of the Council met for the purpose of discussing matters relating to Institution activities generally which had arisen on the outbreak of hostilities. This Committee submitted a full report at a special meeting of the Council held on the 5th October, 1939, as a result of which it was agreed by the Council that every effort should be made to carry on as many as possible of the activities of The Institution during the period of the war in the same way as hitherto, and that the Library and Headquarters should remain for the time being in the present building at Savoy Place, W.C.2.

With considerable reluctance, however, it was felt to be advisable, especially in view of the expressed desire of the Government that owing to air-raid risks no gatherings of the general public should take place, and also to the fact that it would be especially undesirable for numbers of technical experts to collect together, to cancel the programme of London meetings for the first half of the Session, subject to this policy being reviewed if and when conditions changed. As regards the programmes of the Local Centres, Sub-Centres and Students' Sections, it was appreciated that in most areas there would be the same difficulties in holding meetings as in London, but that the final decision was one which could be taken only by each individual Committee in the light of the local conditions and of the views of the local authorities.

As an alternative to the London meetings it was decided that a complete list of the papers that were to have been read should be issued to members, with an intimation that advance copies could be obtained on application to the Secretary and that the submission of written comments on any papers would be welcomed with a view to publication in the *Journal* in the form of discussion, with the author's reply, when the paper itself was published in due course. By this means it was hoped to continue to provide material for the *Journal* on the same lines as hitherto.

This policy was explained to members in circular letters on the 16th October and 26th October, the second of which accompanied a copy of the Presidential Address by Mr. Johnstone Wright, and gave particulars of the papers of which copies would become available.

The Emergency Committee reviewed the position at the end of November, 1939, and in the light of the existing situation, and in deference to the growing desire for more active interchange of views, decided to recommend that meetings should be resumed.

By this time the blackout of the building had been completed, together with adequate air-raid shelter facilities (see paragraph 14). The Council accordingly, at their meeting on the 7th December, adopted the recommendation of the Emergency Committee and The Institution's activities in London were again put into operation with the exception of the usual social functions, which it was not considered appropriate to hold. Full programmes of Ordinary Meetings, meetings of the three technical Sections and Informal Meetings were accordingly arranged by the appropriate Committees for the second half of the Session. The first meeting to take place was the Ordinary Meeting on the 25th January, 1940, when there was a gratifying attendance of over 400 members

The final decision regarding activities in the Local Centres and Sub-Centres was again left to the local Committees, and it will be seen from paragraph (23) that in general they have found it possible to adopt a similar policy.

It has been decided by the Council that the Emergency Committee shall continue in being to deal with any urgent matters that may arise from time to time.

(9) VOLUNTARY NATIONAL SERVICE

It was announced in the Annual Report for 1938–39 that The Institution was co-operating with the Ministry of Labour and National Service in connection with a Central Register of professional persons who would be prepared in war-time to do appropriate paid work of national importance.

Particulars of the scheme were circulated to members of all classes in the United Kingdom, except Companions and Students, and members who were not prepared to volunteer for National Service were asked to complete a special Registration Card giving a statement of their qualifications for the records of The Institution.

The response has been as follows:—

Central Register	
Number of Volunteers	5 540
Cards returned for record purposes ..	3 077
	8 617

When war was declared the Register was put into active operation and, in order to meet the immediate demand for personnel in the telecommunications (and more particularly radio) branches, it was decided to increase the register to include qualified members of the Radio Manufacturers' Association and others known to members of the Wireless Section who had academic qualifications. In addition, it was decided to set up a Subsidiary Register and to invite Students of The Institution who had qualifications or experience in telecommunications to enrol.

The result was as follows:—

Subsidiary Register	
Number of volunteers	260
Cards returned for record purposes ..	787
	1 047

As a means of providing technical personnel for branches of the industry in which there was a probability of a shortage, The Institution has had under discussion with the Minister of Labour the formation of a training pool for engineers possessing suitable basic technical qualifications.

Placing Panels have met frequently since the outbreak of war. As a result, 884 names have been submitted to fill 420 vacancies, and a large number of appointments have been confirmed up to date.

(10) MILITARY SERVICE

Enlistment.

Before the outbreak of war, an arrangement was made with the War Office to ensure that members who were called up for service under the Military Training Act, 1939, would be posted to technical branches of the Forces, and this arrangement was subsequently extended to cover members called up under the National Service (Armed Forces) Act, 1939. In order to effect this procedure, statements of membership have been supplied to members for the information of Placing Officers. Except in a very few instances, the arrangement has been entirely successful.

A small number of members, mostly Graduates and Students, had enrolled for service in non-technical units in the Territorial Army before the outbreak of war. These cases, when brought to the notice of The Institution, have been referred to the appropriate Departments of the Services and, in a large majority of cases, transfers to technical branches have been effected.

Age-Limit Students.

The Council are anxious to avoid a break in membership owing to Students joining His Majesty's Forces, and have therefore allowed such Students to extend the period during which they can remain in that class by a period equal to the length of their service with the Forces.

Postponement of Military Service.

The National Service (Armed Forces) Act, 1939, provides that students who are nearing the completion of their studies for important examinations may apply for postponement of service, but it was found that from patriotic motives there was reluctance to apply. The Council feel that it is most important for Students to complete their studies so that:—

(*a*) They will be of greater value to the Services when called up, and

(*b*) Industry will continue to be provided with fully trained engineers.

With this end in view, representations have been made to the Ministry of Labour, and Students have been informed of the Council's attitude through the medium of the *Students' Quarterly Journal.* Members will be aware that since the end of the period covered by this Report an amendment has been made to the Schedule of Reserved Occupations which will ensure that part-time students, engineering apprentices and learners will be enabled to complete their studies.

Members serving with His Majesty's Forces.

It has been decided to publish from time to time in "Institution Notes" in the *Journal* the names of members who are serving with His Majesty's Forces, together with particulars of their rank and the Unit in which they are serving. Three such lists have already been published comprising 705 names. It is also proposed to publish lists of promotions, transfers, honours awarded, etc. In order that these lists may be as complete as possible it is hoped that members concerned will supply the Secretary with information not only regarding themselves but also in connection with other members of whom they may have knowledge.

(11) DEFENCE SERVICES

A letter was sent on behalf of the Council in November last to the three Defence Services and to the Ministry of Supply advising them that The Institution is continuing to function as far as possible in the normal way, and offering to give them any assistance or information which may be needed from time to time.

(12) I.E.E. HOME SECURITY ADVISORY COMMITTEE

The Council have set up a Committee to assist the Ministry of Home Security in electrical matters. In particular, the Committee have collaborated with the British Standards Institution in the preparation of Specifications dealing with the electrical equipment of air-raid shelters, and have also under consideration problems in connection with restricted street lighting.

(13) INSTITUTION BUILDING

As in past years the use of The Institution's premises has been granted without charge to a number of kindred

societies in connection with their meetings, and 85 such meetings have been held during the past year. It will continue to be the policy of the Council to grant the use of the building to sister Institutions on every possible occasion as long as this does not conflict with the ever growing requirements of The Institution itself.

After prolonged tests with experimental apparatus there has been installed in the Lecture Theatre a loud-speaker installation with microphones for the use of authors, lecturers, and speakers in discussions. It is hoped that all speakers will make a practice of using this equipment so that they may be more easily audible to everyone present.

The opportunity is taken to draw attention to the facilities available in the Theatre for demonstrations and experiments and to the fact that an excellent epidiascope is available, so that not only lantern slides but also such articles as photographic prints as well as other opaque objects can be exhibited on the lantern screen. It is thought that the availability of this apparatus is not widely enough appreciated by speakers.

(14) AIR RAID PRECAUTIONS

Appreciable structural work has had to be effected in the basement of the Institution building, in compliance with the Civil Defence Act, 1939, to provide adequate air-raid shelters for the regular occupants of the building, including the tenants' staffs. An emergency system of secondary lighting has also been installed as part of these precautions. The shelters, which will accommodate 250 persons, are also available for use in emergency for visitors to evening meetings, and to provide for any attendance beyond this number permission has been obtained from the owners of adjoining premises for the use of their shelter, which is readily accessible from the Institution building. Those attending meetings in the building are asked, should emergency arise, to put themselves under the guidance of members of the Institution staff who have been trained in A.R.P. duties and also to pay careful attention to the instructions which are clearly displayed in appropriate parts of the building.

In addition to these precautions, the Council have had to provide for the possibility of an emergency evacuation of the building, and for this purpose have rented for the duration of the present hostilities two adjoining houses in Weybridge, Surrey. One of the houses will be used as offices and the other as a hostel for those members of the staff who, by reason of travelling difficulties, would be compelled to live in, and both these houses have been prepared with the necessary services to enable the offices and staff to be transferred there at short notice. Evacuation to Weybridge will only be effected if conditions become such as to make the conduct of The Institution's affairs in London too difficult, and it is hoped in any event to keep the building open by means of a nucleus staff and to maintain the Reference and Lending Libraries in London, where it is thought they will be of the greatest practical use.

Special regard has had to be given to the safety of other property and records of The Institution, and those which are of greater value or are irreplaceable have been removed either to Weybridge or elsewhere.

(15) EXAMINATIONS

From and including November, 1939, the name of The Institution's examination was changed from the Graduateship Examination to the Associate Membership Examination. No change whatever was made in the subjects, syllabuses or standard of the examination.

Examinations were held for a total of 666 candidates in May and November, 1939, in London, Belfast, Birmingham, Cardiff, Dublin, Glasgow, Loughborough, Manchester and Newcastle-on-Tyne, and also, in November only, in Argentina, Australia, Ceylon, China, Egypt, Federated Malay States, India, Malta, New Zealand, Nigeria, South Africa and South Iran.

Examinations in English only were also held in May and November, 1939, at various centres in Great Britain for 248 holders of National Certificates in Electrical Engineering.

In addition 21 theses, submitted by candidates who were permitted by the Council to do so as an alternative to sitting for the Graduateship (now Associate Membership) Examination, were examined. The Page Prize was awarded to Mr. O. H. Hosking for his thesis entitled "Aerial Warfare and the Maintenance of Electricity Supply." This Prize is offered annually for the best paper or thesis submitted in lieu of the Examination, provided that one has been received of sufficient merit to justify an award.

(16) NATIONAL CERTIFICATES AND DIPLOMAS IN ELECTRICAL ENGINEERING

England and Wales.

In 1939 the Joint Committee, representing the Board of Education and The Institution, were associated with the final examinations of 249 courses at colleges and schools in England and Wales, approved in connection with the above certificates and diplomas.

The final examinations were held during the summer, and the number of awards was as follows:—

Ordinary Certificates	1 133
Ordinary Certificates endorsed ..	2
Higher Certificates	421
Higher Certificates endorsed ..	79
Ordinary Diplomas	48
Higher Diplomas	8
Total	1 691

Scotland.

In conjunction with the Scottish Education Department, The Institution was associated with 16 courses in Scotland during the year under review.

The final examinations were held during the summer, and the number of awards was as follows:—

Ordinary Certificates	49
Higher Certificates	14
Higher Certificates endorsed ..	3
Higher Diplomas	8
Total	74

(17) SCHOLARSHIPS

The following Scholarships were awarded by the Council during the Session:—

Ferranti Scholarship

(Annual Value £250; tenable for 2 years.)
A. E. Chester, M.Sc. (Manchester University).

Duddell Scholarship

(Annual Value £150; tenable for 3 years.)
D. E. Thomas (St. Clement Danes Grammar School, London).

Silvanus Thompson Scholarship

(Annual Value £100, plus tuition fees; tenable for 2 years.)
*L. E. Ebourne (Cadbury Bros., Ltd., Birmingham).

William Beedie Esson Scholarship

No award.

Swan Memorial Scholarship

(Value £120; tenable for 1 year.)
A. M. Davies, B.Sc.(Eng.) (City & Guilds College, London).

David Hughes Scholarship

(Value £100; tenable for 1 year.)
F. Rushton (Manchester College of Technology).

Salomons Scholarship

(Value £100; tenable for 1 year.)
T. E. Calverley (King's College, London).

Paul Scholarship

(Annual Value £50; tenable for 2 years.)
D. Nightingale (Stanley Technical Trade School, London).

Thorrowgood Scholarship

(Annual Value £25; tenable for 2 years.)
E. Outhwaite (London and North-Eastern Railway).

War Thanksgiving Education and Research Fund (No. 1)

Grant of £50 to:
† R. K. Beattie, M.Sc. (Manchester University).

Grants of £25 each to:
‡ P. H. Longman (Queen Mary College, London).
§ G. F. Shute (University College, Nottingham).

All the scholarships and grants mentioned above may be awarded annually, with the exception of the Paul and William Beedie Esson Scholarships, which are awarded in alternate years only. When an award of the latter scholarship is renewed for a third year, however, the next award is deferred for a year.

Bequest.

The Council record with appreciation a bequest of approximately £3 000 to The Institution under the will of the late Mr. William Guy-Pell "for the foundation of a Scholarship or Scholarships of such a nature as the Council of that Institution think fit and to be called after my natal name of Geipel." This sum will pass to The Institution after the decease of the testator's wife and son, for whom it is being held in trust.

* At present on military service; scholarship in abeyance.
† Since deceased.
‡ At present on military service; grant in abeyance.
§ At present on work of national importance; grant in abeyance.

(18) MEMBERS WHO HAVE RETIRED OR WHO ARE OF LONG STANDING

The Council wish to draw attention to the existence of a rule which has been in operation for some years and which enables members who have retired from the profession and are still desirous of retaining their membership of The Institution to do so without payment of further subscriptions. The rule is as follows:—

> "Any Corporate Member who has reached the age of 60 and has retired from the practice of his profession or business may apply to the Council to remit his future annual subscriptions, provided that his membership of The Institution has been continuous for at least 25 years. If he desires to have the publications of The Institution he will receive them on payment of £1 1s. per annum."

In addition to the foregoing it should be noted that a further rule provides that as soon as a member of any class has completed 50 years of membership he will cease to be asked to pay any further subscriptions, regardless of whether he is still in remunerative employment. This Rule operates automatically and the member qualifying need not make application to The Institution.

(19) APPEAL FOR THE HERTZ FAMILY

The attention of the Council has been drawn to the circumstances of the widow and two daughters of Heinrich Hertz, who, as refugees from Germany, have been living in this country for some time.

As a result of careful inquiries, the Council were entirely satisfied that the circumstances warranted an appeal for financial assistance, and they therefore asked associations and companies who have benefited by the discoveries of Hertz to subscribe to a Fund.

The result of the appeal was as follows:—

	£	s.	d.
Electric and Musical Industries, Ltd. ..	100	0	0
Standard Telephones and Cables, Ltd. ..	100	0	0
British Broadcasting Corporation ..	50	0	0
British Thomson-Houston Co., Ltd. ...	50	0	0
Ferranti, Ltd.	50	0	0
South African Institute of Electrical Engineers	50	0	0
Murphy Radio, Ltd.	20	0	0
General Electric Co., Ltd.	10	10	0
Lancashire Electric Power Co.	10	10	0
Smaller contributions aggregating ..	19	19	0
	£460	19	0

(20) HISTORY OF THE INSTITUTION

The preparation of a History of The Institution, reference to which has been made in past Annual Reports, was completed last autumn and publication was effected at the end of October. The preparation of the book was entrusted by the Council to Mr. Rollo Appleyard, with the suggestion that it should relate chiefly to the 60 years from 1871, when The Society of Telegraph Engineers was founded, to 1931, which marked the centenary of the discovery by Michael Faraday of the evolution of electricity from magnetism. It was recog-

nized, however, that there could be no rigid adherence to these limits. An introductory chapter takes account of the state of electrical knowledge prior to 1871, and a concluding chapter contains a brief account of the historic site on which the Institution building now stands.

The History is a crown quarto volume containing 342 pages and 38 plates, and is bound in full art canvas. About 1 500 copies have already been disposed of, and copies are still available for purchase by members at the specially reduced price of 12s. 6d. each. The price to the public is 18s. 6d. per copy.

(21) PREMIUMS

The Premiums awarded by the Council for papers read at meetings or accepted only for publication in the *Journal* will be announced about the time of the Annual General Meeting.*

Owing to the cancellation of meetings during the first half of the Session, the retiring President, Dr. A. P. M. Fleming, C.B.E., was unable to follow the usual custom of presenting the Premiums for 1938–39 to their recipients at the opening meeting. The Premiums were therefore despatched direct to the recipients under cover of a personal letter from Dr. Fleming.

The award of the Willans Premium (which is made triennially, alternately by this Institution and The Institution of Mechanical Engineers, for the best paper read or published since the last award by the Institution concerned dealing with "the utilization or transformation of energy treated especially from the point of view of efficiency or economy") fell this year to this Institution. The Council selected for the award the paper on "Rural Electrification" by Mr. J. S. Pickles, B.Sc.Tech. (*Journal I.E.E.*, vol. 82, p. 333).

The award (value approximately £15) may, at the choice of the recipient, take the form of a medal, books, etc., or cash.

(22) MEETINGS

During the past 12 months 346 meetings have been held in London and at the Local Centres by the members, the Council, and the various Committees. A detailed statement is given in Appendix B.

The average attendance at the 8 Ordinary Meetings held in London for the reading and discussion of papers was 256, compared with 251 for last Session. In addition, two purely formal meetings for the election and transfer of members were held during the first half of the Session.

(23) LOCAL CENTRES AND SUB-CENTRES

As mentioned in paragraph 8, the Council, when settling the policy to be followed with regard to the holding of meetings in London, left it to each Local Centre and Sub-Centre to decide on its own policy, having regard to local conditions. The majority of the Local Centres and Sub-Centres decided on cancellation, some held a meeting for the delivery of the Chairman's Address, and one or two arranged to carry on as far as possible with the normal programme. When the Council decided to resume London meetings during the second half of the Session, although it was again left to the local Committees, the majority once again followed suit and also resumed meetings. Full details of such Local Centre and Sub-Centre activities are contained in the Annual Reports presented to the local members. The Council wish to place on record their keen appreciation of the efforts of the officers and committees of the Local Centres and Sub-Centres, especially in the present difficult times, and to pay tribute to the value of the Centres and Sub-Centres in the organization of The Institution.

Few of the Local Centres and Sub-Centres have held social functions, and owing to this the President and the Secretary have been deprived of the usual opportunity of paying visits. It is a matter of sincere regret that because of urgent matters and the difficulties of travel it has proved impracticable for them to attend any General Meetings of the Centres. The President, however, together with the Secretary, attended the Annual Dinner of the Tees-Side Sub-Centre, with which in the early days Mr. Johnstone Wright was closely connected.

Owing to the many extra commitments occasioned by the war, and the advisability of curtailing travelling, the Vice-Presidents were unable to carry out the usual programme of visits to the Local Centres and Sub-Centres under the scheme referred to in previous Annual Reports. The matter has, however, been kept under review and, when circumstances were favourable, it has been found possible for a Vice-President, and in one instance a Past-President, to fit in a visit with a journey necessarily made on national business.

Members are reminded that local technical library facilities are available at Birmingham, Dublin, Dundee, Liverpool, Edinburgh, Glasgow, Leeds, Loughborough, Manchester, Middlesbrough, Newcastle-on-Tyne, Portsmouth and Southampton. Full details of the arrangements for borrowing or referring to the books in these libraries can be obtained on application to the local Honorary Secretaries.

The Annual Meeting of the Honorary Secretaries of Local Centres and Sub-Centres was held in London on the 25th January, 1940, when matters of common interest in regard to local organization and administration were discussed.

In common with some other engineering Institutions, The Institution in April last sent the Chief Engineers in the various Commands of the Royal Engineers general invitations for all R.E. Officers to attend meetings of the Local Centres and Sub-Centres.

In April 1939, the Council approved revised Bye-laws for the North-Eastern Centre, the Tees-Side Sub-Centre and the North-Eastern Students' Section.

(24) METER AND INSTRUMENT SECTION

The membership of the Meter and Instrument Section is now 733. Five meetings of the Section have been held during the past year, the average attendance being 91, which compares with 114 during the preceding 12 months. The meetings included one devoted to an informal discussion. Demonstrations of apparatus accompanied papers whenever practicable, and added greatly to the interest and success of the meetings.

The Committee wish to remind the members that short demonstrations of apparatus and processes which come within the scope of the Section will be welcomed.

* See page 610.

These need not necessarily relate to the subject matter of the paper being read on the same evening.

The Summer Visit for 1939 took place on Saturday, 6th May, when a party consisting of about 90 members and ladies visited the Post Office Research Station at Dollis Hill and afterwards proceeded to Windsor Castle, where the afternoon was spent. The Section Committee wish to record their thanks for the hospitality accorded on this occasion.

The Section Dinner was arranged to take place on Friday, 17th November, 1939, but was cancelled on account of the war.

(25) TRANSMISSION SECTION

The Transmission Section now has a membership of 1 683. Four meetings have been held during the past year, the average attendance being 82 compared with 98 during the preceding 12 months. The papers have been of a high standard and have been followed by excellent discussions.

A week-end visit was paid to Ireland from the 19th to the 23rd May, 1939, 57 members taking part. The itinerary included both Dublin and Belfast and visits were made to the Pigeon House generating station, the Inchicore outdoor transformer station, and the work in progress for the new power station of the Eire Electricity Supply Board at Poulaphouca, the Rosebank Switching and Control Station of the Electricity Board for Northern Ireland, the Harbour Power Station of the Belfast Corporation Electricity Department, and the Shipbuilding and Engineering Works of Harland and Wolff, Ltd. The party also enjoyed the hospitality of the electrical and allied manufacturers in Belfast.

The thanks of the Section are due to the firms and authorities in Ireland, and to the Chairmen, Honorary Secretaries and Committees of both the Irish Centre and the Northern Ireland Sub-Centre, for the excellent arrangements made and the hospitality accorded to the party throughout the visit.

The Summer Visit of the Section was, by the kind invitation of the Yorkshire Electric Power Company, to have been held in Yorkshire on Saturday, 16th, and Sunday, 17th September, 1939, but the outbreak of war necessitated its cancellation.

For the same reason the Section's Annual Conversazione and Dance which was to have been held on Wednesday, 1st November, 1939, was cancelled.

(26) WIRELESS SECTION

The membership of the Wireless Section is now 1 087. Four meetings have been held during the past year, at which 4 papers were read. In addition, 13 papers have been published or accepted for publication in the *Journal*. The average attendance at the meetings was 125, compared with 195 last Session.

One Informal Meeting of the Section has been held and the attendance was well up to the average.

The Summer Visit for 1939 took place on Saturday, 27th May, 1939, when a party consisting of 60 members visited the Post Office Ray Diversity Station, Cooling Marshes, Rochester. Thanks have been accorded to the Engineer-in-Chief for the arrangements made to receive the party.

(27) SUGGESTED NEW SECTION

It was mentioned in the last Annual Report that consideration was being given to a suggestion that an Installation Section of The Institution should be set up. There is a general feeling that such a Section, to cover not only Installation but also Utilization, would fill a definite place in the activities of The Institution, and a scheme for the setting up of the Section was well advanced at the outbreak of war. It has been decided that the conditions prevailing at present would not conduce to the successful inauguration of any new Section, but the groundwork has been prepared with a view to this new activity being started as soon as conditions permit.

(28) INFORMAL MEETINGS

The curtailed programme reduced the number of Informal Meetings to six for the Session. This included one joint meeting with the Institutions of Civil Engineers and Mechanical Engineers, an invitation to attend which was extended to members of the Institute of Welding. The attendance on this occasion numbered 132 and the average attendance for the session is 87, as against 65 last year.

The Informal Meetings Committee again cordially invite members to write to the Secretary indicating subjects which they wish to suggest for discussion. Offers from members to open discussions will also be welcomed and carefully considered by the Committee.

The Council wish to remind the younger members, and particularly those who have not yet attended any of the meetings, that these are arranged primarily for them, with the object of their gaining experience in public speaking and thereby acquiring confidence to take part in the discussions on papers at the Ordinary Meetings.

The proceedings of the Informal Meetings are not reported by the Press, and only a précis of the discussions (prepared by a member of the Committee) is sent to the technical journals for publication.

(29) STUDENTS' SECTIONS

Programmes of meetings, visits to works, and social functions, details of which have been given from time to time in the *Students' Quarterly Journal*, have been carried out during the second half of the Session by the nine Students' Sections at London, Birmingham, Bristol, Glasgow, Leeds, Liverpool, Manchester, Newcastle-on-Tyne and Sheffield. During the first half, the majority of the Sections decided to follow the Council's lead with regard to London meetings and cancelled their programmes.

The membership of the nine Sections is in the aggregate 4 392, which includes 1 971 Graduates.

Owing to difficulties in running the Sections caused by the calling-up for military service of members of Committees, the Council decided in February last to alter their Rules for Students' Sections so as to allow Graduates who so desire to continue during the period of the war their membership of Students' Sections after the end of the year in which they attain the age of 28. So far 81 Graduates have taken advantage of this alteration.

In July last the Council approved a number of amendments to their Rules for Students' Sections, some of which were suggested by the Annual Conference of Honorary Secretaries of Students' Sections, others being either of an editorial character or intended to bring the existing Rules into line with the corresponding Rules for Local Centres and Sub-Centres.

The Students' Lectures were delivered this Session by Mr. J. W. Beauchamp and Mr. A. Duxbury, who visited the following places:—

Lecturer.	*Subject.*	*Place.*
Mr. J. W. Beauchamp	" Electricity—its Reaction on Human Affairs "	Glasgow Leeds Newcastle-on-Tyne
Mr. A. Duxbury	" Public Speaking "	London Birmingham Liverpool

The total attendances at the six lectures were approximately 284, compared with 471 for the 10 lectures given last Session.

The Ninth Annual Meeting of the Honorary Secretaries of the Sections was held in London on the 26th January, 1940, when a useful discussion took place on points of common interest.

The *Students' Quarterly Journal* has naturally been under consideration in view of the present altered circumstances, and it has been decided to maintain this publication in as active a form as possible. With a view to ensuring an adequate supply of copy, arrangements have been introduced to make the various papers which are read at the different Sections available for publication immediately after the meetings, instead of waiting till the end of the session.

There has, however, been a welcome maintenance of the supply of articles submitted direct for publication and there is every indication that the *Students' Quarterly Journal* will continue to flourish.

In view of paper restrictions the number of pages has necessarily been reduced, and there will be a shortening of the articles in consequence so that the necessary variety can be maintained. There is no doubt that the continued appearance of this publication is appreciated, particularly by Students and Graduates serving with the Forces.

In August last a Summer Meeting to the Massif Central Region of France was organized by the London Students' Section. The party, numbering 50 and including members from nearly every Students' Section, had a most successful tour, which included visits to hydro-electric stations in the region. A full account of the Meeting was given in the December, 1939, issue of the *Students' Quarterly Journal*.

The London Students' Section this year succeeded in regaining the " Young " Trophy in the Sports Contest with the Students and Graduates of the Institutions of Civil and Mechanical Engineers. The Section held the Trophy for the first 3 years of the Contest (1934–36), and since then it has been held in turn by The Institution of Civil Engineers and The Institution of Mechanical Engineers. The Contest in 1939 again consisted of cricket, tennis, and shooting matches, and a full account appeared in the September, 1939, issue of the *Students' Quarterly Journal*.

(30) LOCAL HONORARY SECRETARIES ABROAD

During the Session the Council appointed Mr. A. B. Cooper as Local Honorary Secretary of The Institution for Canada in place of Dr. F. A. Gaby, who had resigned from this office, and Dr. W. Lulofs as Local Honorary Secretary for Holland in place of the late Mr. A. E. R. Collette.

The Council also appointed Mr. P. H. Mason as Local Honorary Secretary for New Zealand in place of Mr. J. McDermott, who resigned the office. It is with regret, however, that The Institution has since learned of Mr. Mason's death, and the appointment of his successor is under consideration.

(31) ACTIVITIES OF OVERSEAS MEMBERS

The Overseas Activities Committee of the Council are gratified that the activities of The Institution overseas have been maintained. Details have been received of meetings at which papers have been read and discussed, and of visits and other functions arranged by the Argentine and China Local Centres and by the Overseas Committees in Queensland, Western Australia, Bombay, Calcutta, Lahore and Madras.

In some instances papers already read in London have been read and discussed, and papers have also been written and presented by local members.

The schemes of co-operation with other Institutions in Argentina, China and Malaya continue to operate satisfactorily.

The eighth Annual Conversazione and Reunion of members from overseas and their ladies was held in the Institution Building on Tuesday, 13th June, 1939. The total attendance was about 135 and the arrangements were similar to those made in previous years. An account of the proceedings was published in the *Journal* for September, 1939 (vol. 85, page 468).

The Council are always anxious that The Institution should do everything possible to assist members from overseas; but more particularly in the present circumstances members coming from overseas, whether in civilian capacities or in connection with the fighting forces, will be especially welcome at The Institution. A letter to this effect has been addressed to all Honorary Secretaries of The Institution abroad asking them to make the fact as widely known as possible.

(32) CO-OPERATION AMONG ENGINEERING INSTITUTIONS

As mentioned in the last Annual Report a Joint Committee, known as the Joint Committe on Engineering Co-operation Overseas, on which the eight constituent Institutions of the Engineering Joint Council are represented, has been set up to consider the possibility of fostering co-operation among overseas members of these Institutions and, where there is a local Engineering Institution in existence, with the members of that Institution, and to promote such co-operation in those countries as may be found to be practicable.

The possibility of advancing co-operation in Great Britain wherever practicable is always before the Council, and, apart from Joint Meetings with kindred Institutions, members of such Institutions are always welcome at meetings of The Institution at which papers of special interest to them are being read.

Co-operation is also general in the areas of the Local Centres, where the local Committees have done much to encourage such activity.

(33) REVIEWS OF PROGRESS

Continuing the series of reviews of progress in electrical engineering which have appeared in the *Journal* each year since 1926, reviews on the following subjects have been published during 1940:—

Electrical Plant and Machinery.
Electricity applied to Ships.
Electro-Physics (including the Photo-electric Cell).
Electrical Illumination.
Factory Applications.

Arrangements have been made for reviews on the following subjects in 1941:—

Agricultural Applications of Electricity.
Domestic Applications of Electricity.
Electrical Insulating Materials.
Electrical Measuring Instruments and Integrating Electricity Meters.
Transmission and Distribution.

(34) FARADAY LECTURE

It was decided by the Council that in view of the prevailing conditions the arrangements for the delivery of the Faraday Lecture, which was to have been given this Session by Mr. C. E. Fairburn, M.A., on the subject of "Electric Traction," should not be proceeded with. The question whether the lectures can be resumed next Session is receiving consideration.

(35) SUMMER MEETING

In response to an invitation from the Committee of the North-Western Centre a Summer Meeting was held at Manchester from the 19th to the 23rd June, 1939, and some 240 members and ladies took part. The programme commenced with an Informal Reunion, which was followed during the succeeding days by visits to:—

The Exide Works of the Chloride Electrical Storage Co., Ltd.
The Handkerchief Factory of Tootal Broadhurst Lee Co., Ltd.
The Kearsley Power Station and the Domestic Appliance and Meter Testing Station of the Lancashire Electric Power Co., Ltd.
The Barton Power Station of the Manchester Corporation Electricity Department.
The Oil Refinery of the Manchester Oil Refinery, Ltd.
The Trafford Park Works of Metropolitan-Vickers Electrical Co., Ltd.
The Irlam Steel Works of the Lancashire Steel Corporation, Ltd.
The Irlam Soap Works of the Co-operative Wholesale Society, Ltd.
The Park Works of Mather & Platt, Ltd.

Evening receptions were given by the Lord Mayor and the Lady Mayoress of Manchester, the Mayor and Mayoress of Salford and the Council of the University of Manchester. At the last-mentioned reception the guests inspected the University Laboratories.

The programme also included a whole-day excursion to Lake Windermere, and ended on the evening of the 23rd June with a dance and cabaret with Metropolitan-Vickers Electrical Co., Ltd., as hosts.

The thanks of The Institution have been conveyed to all those mentioned above, and the Council wish to place on record their appreciation of the generous hospitality received. They also record their high appreciation of the work of the Committee of the North-Western Centre and in particular of the Chairman of the Centre (Mr. W. Fennell) and the Hon. Secretary (Mr. L. H. A. Carr).

(36) COOPERS HILL WAR MEMORIAL PRIZE

The award of the Coopers Hill War Memorial Prize, which consists of a bronze medal, a parchment certificate, and a money prize of £20, falls this year to The Institution, and the Council have decided to invite members to submit for consideration a paper on any subject coming within the scope of Electrical Science or Electrical Engineering and their Applications. Papers must be written specially for the purpose of the competition.

Only Corporate Members of The Institution under 35 years of age are eligible to compete. The Prize consists of two awards, one of which is made annually by The Institution of Civil Engineers, and the other triennially in turn by The Institution of Electrical Engineers, the School of Military Engineering, Chatham, and the School of Forestry, Oxford.

(37) CHINESE ELECTRICAL ENGINEERING APPRENTICES AND STUDENTS

Mention has been made in previous Annual Reports of the Council's decision that facilities to attend Institution meetings and to use the Reference Library should, as a gesture of goodwill, be offered to Chinese electrical engineering apprentices and students who, under arrangements made by the Federation of British Industries, had been given opportunities for gaining engineering experience in Great Britain. The arrangement has again been continued this Session, and some 18 young men, whose names have been supplied by the Federation, come within the scope of the scheme at the present time. Those who are engaged in the provinces have, with the ready co-operation of the Local Centres and Sub-Centres concerned, been granted privileges as regards attendance at local meetings and the use of such library facilities as may be available.

(38) ANNUAL CONVERSAZIONE

The Annual Conversazione was held on the 4th July, 1939, at the Natural History Museum, London. The total attendance of members and guests was 2 250.

(39) ANNUAL DINNER

The Annual Dinner, which in the ordinary course of events would have been held on the 8th February, was cancelled in consequence of the war.

(40) ANNIVERSARY CELEBRATIONS AND CONFERENCES

During the year under review The Institution has been represented at the following Anniversary Celebrations and Conferences, etc.:—

Name of Body	*Nature and Date of Function*	*Name of I.E.E. Representative*
Association of Teachers in Technical Institutions	Annual Conference, Southport (27–30 May, 1939)	E. L. Morland
International Commission on Illumination	Plenary Meeting, Holland (12–20 June, 1939)	Lt.-Col. K. Edgcumbe, T.D. Prof. J. T. MacGregor-Morris
Royal Sanitary Institute	Annual Health Congress, Scarborough (3–8 July, 1939)	W. K. Fleming

In addition, invitations were accepted, and the representatives indicated were appointed, to attend the following meetings which, owing to the outbreak of war, did not take place:—

Name of Body	*Nature and Date of Function*	*Name of I.E.E. Representative*
Commission Mixte Internationale	5th Plenary Meeting, Paris (1–8 April, 1940)	C. W. Marshall
National Smoke Abatement Society	11th Annual Conference, Blackpool (21–23 Sept., 1939)	W. E. Swale
Schweizerischer Elektrotechnischer Verein	Annual Meeting and Jubilee Celebrations, Zürich (2–4 Sept., 1939)	H. S. Hvistendahl
Verband Schweizerischer Elektrizitätswerke	Annual Meeting, Zürich (2–4 Sept., 1939)	H. S. Hvistendahl
Union of Lancashire and Cheshire Institutes	Centenary Celebrations, Manchester (9–10 October 1939)	W. Fennell L. H. A. Carr

(41) NEW ZEALAND CENTENNIAL ENGINEERING CONGRESS, 1940

An intimation was received in December last from the organizers that the above Congress, which was to have been held in Wellington in February, 1940, to form part of the celebrations of the Centenary of the official founding of New Zealand, had been cancelled in view of the international situation. In response to a suggestion of the Executive Committee, arrangements had been made by The Institution for two papers to be presented, one by Dr. A. P. M. Fleming, C.B.E., (who was appointed by the Council as The Institution's representative at the Congress) on " The Influence of Research and Education on the Electrical Engineering Industry in Great Britain," and the other by Messrs. E. Fawssett, H. W. Grimmitt, G. F. Shotter and H. G. Taylor, M.Sc.(Eng.), on " Practical Aspects of Earthing," which was read at the meeting of the Transmission Section on the 14th February, 1940. These papers were duly forwarded, as it was understood to be the Executive Committee's intention to proceed with the publication of papers notwithstanding the cancellation of the Congress itself.

(42) LIBRARY

During the year, 371 books and pamphlets have been presented to the Reference Library by members and others, and 86 volumes were purchased. The total number of readers for the year was 5 587, of whom 784 were non-members, as against 7 233 and 1 013 respectively in 1938–39.

Seventy-one new volumes have been added to the Lending Library, and 2 224 books were issued to 1 042 borrowers, the corresponding numbers for the previous year being 2 910 and 1 196 respectively.

(43) GIFT TO THE INSTITUTION

The Council express their cordial thanks to the donor of the following gift to The Institution:—

Donor.	*Gift.*
Mr. F. G. Hyland	Specimen of the Calcutta–Diamond Harbour experimental telegraph line laid in 1851.

(44) THE JOURNAL OF THE INSTITUTION

The total number of pages in the two volumes of the *Journal* for 1939 was 1 580 (excluding Plates), as compared with 1 624 in the two 1938 volumes.

Owing to the Paper Controller's restriction on the total amount of paper that can be supplied to The Institution, the number of pages in recent monthly issues of the *Journal* has had to be considerably reduced, with the result that publication of several papers and discussions from last Session has been delayed.

As a result of discussions which the Secretary had with the Press and Censorship Bureau shortly after the outbreak of war, it became clear that it would be inadvisable for The Institution to rely on its own censorship of papers and the *Journal* with a view to preventing the publication of information likely to be of strategic value to the enemy in connection with the prosecution of the war. Arrangements have therefore been made whereby all matter accepted by The Institution for publication in any form is voluntarily submitted to the Bureau for censorship.

(45) REGULATIONS FOR THE ELECTRICAL EQUIPMENT OF BUILDINGS

A revised edition (Eleventh) was issued in June, 1939, and there has already been a great demand for copies. The arrangement of sections adopted in the Tenth Edition has been retained, and the numbering of the

clauses has been preserved as far as possible. The majority of the alterations were the result of comments and suggestions received since the Tenth Edition was published.

A Supplement containing a number of alterations, mostly of a minor nature, was issued in February, 1940. Copies of the Supplement can be obtained free of charge, on application to the Secretary, for insertion in existing copies of the Regulations.

(46) REGULATIONS FOR THE ELECTRICAL EQUIPMENT OF SHIPS

A revised edition (Third) was issued in September, 1939, with a view to bringing the Regulations up to date; at the same time the Regulations were rearranged so as to make their form similar to that of the Regulations for the Electrical Equipment of Buildings. Important features of the new edition are simplified numeration, the inclusion of clauses dealing with electric propulsion plant and with electric signs, and recommendations in connection with the suppression of electrical interference with radio apparatus. Particular care was given to the revision and amplification of the special requirements for oil ships.

Suggestions for amendment of the Regulations should preferably be made through one of the Associations or bodies represented on the Ship Electrical Equipment Committee, whose names appear in the preliminary pages of the Regulations.

(47) MODEL GENERAL CONDITIONS FOR CONTRACTS

Clauses dealing with eventualities arising out of the war for use in conjunction with the Model Form of General Conditions A (revised 1938) are being prepared, and these clauses will be published as soon as they are approved by the Council.

Progress is also being made with the revision of the Conditions C for the sale of goods other than cables at home without erection (published, April, 1924).

(48) OPERATING THEATRES ELECTRICAL APPARATUS COMMITTEE

As a result of the war, meetings of the Committee have had to be suspended for the time being.

One of the Sub-Committees mentioned in the last Report has been considering measures to reduce the risk of explosion due to faults in surgical lamps and flexibles, whilst the other Sub-Committee has been investigating the possibility of preventing electrification by artificially increasing the humidity of the air in operating theatres.

(49) L.C.C. BYE-LAWS WITH RESPECT TO THE INSTALLATION, MAINTENANCE AND INSPECTION OF LIFTS, HOISTS AND ESCALATORS

On the 4th July, 1939, the Council had before them a letter (20th June) from the Chief Engineer to the London County Council enclosing copies of draft bye-laws for lifts, etc., and requesting The Institution to submit comments thereon by the 20th July. The Council set up a Special Committee to deal with the draft bye-laws, with power to submit observations direct owing to the urgency of the matter. The Committee held one meeting and on the 19th July submitted their comments to the London County Council. It was pointed out that the comments referred only to the preliminary draft and that they might need reconsideration if a further draft were produced. No further draft has, however, been received.

(50) ENGINEERING PUBLIC RELATIONS COMMITTEE

The Engineering Public Relations Committee, which has been mentioned in previous Annual Reports and upon which The Institution is represented, has during the year decided to restrict its activities instead of proceeding with the original programme proposed. It will act in future only as an advisory body on " the dissemination of knowledge for the general advancement of engineering science by presenting to the public in suitable form information concerning the science and practice of engineering in its services to the public."

Since the outbreak of war, the Committee's normal activities have been suspended, although arrangements have been made for it to meet if necessary to discuss any suggestions for war-time co-operation.

(51) " SCIENCE ABSTRACTS "

The Physics volume of *Science Abstracts* for 1939 contains 4 705 abstracts, compared with 5 081 in 1938. The Electrical Engineering volume contains 2 811 abstracts, compared with 3 622. During the last quarter of 1939 there was a temporary reduction in the number of abstracts from German periodicals owing to delay in obtaining copies, but the arrears were recovered in subsequent months.

Science Abstracts, which appears monthly in two sections, namely Section " A " (Physics) and Section " B " (Electrical Engineering), consists of full abstracts from the leading scientific and technical journals and the proceedings of learned societies of the whole world, and presents in a form convenient for immediate reference a complete and concise record of the progress of physical science and electrical engineering. 1 424 members of The Institution subscribe to *Science Abstracts*, 851 to both Sections, 6 to Section " A " only, and 567 to Section " B " only, but the Council hope that in view of its exceptional value more members will become subscribers to the publication. It may be obtained, if ordered in advance, by Students of The Institution, as well as by Graduates up to the age of 28, at the special rate of 7s. 6d. per annum for both sections, or 5s. for either the Physics or the Electrical Engineering Section, and by all other members of The Institution at 20s. for both Sections, or 12s. 6d. for either Section alone, the rates charged to the general public being £1 15s. per Section, or £3 for both Sections.

A feature of the Annual Index to Section " A " (Physics) which has proved of considerable value since its

introduction in 1934, is the "Supplementary Index of Apparatus and Instruments," in which the papers are classified under the names of the instruments and arranged in alphabetical order.

(52) BENEVOLENT FUND

The donations and subscriptions to the Fund in 1939 amounted to £3 939 6s. 3d., in which are included the proceeds of Golf Competitions organized by the Mersey and North Wales (Liverpool) Centre (£88), the North-Western Centre (£125), the North Midland Centre (£66 2s. 9d.), the Scottish Centre (£6 12s. 0d.) and the Incorporated Municipal Electrical Association (£18 19s. 6d.). In addition to the foregoing, the Fund benefited by the surplus of £240 19s. 2d. on the London Electrical Engineers' Ball in 1939, and £150 from the Summer Meeting at the North-Western Centre. Gifts were received from the organizers of similar functions in the provinces [£30 from the South Midland Electrical Engineers' Ball, £19 8s. 3d. from the Mersey and North Wales (Liverpool) Electrical Engineers' Ball, and £15 15s. from the North-Western Centre Manchester Engineers' Dance Committee]. A special donation of £169 4s. 7d. was received from Mr. H. Marryat.

In the course of 1939, grants were made to 80 persons, amounting to a total of £3 814 15s. 7d. In assisting these cases the Fund also provided for the needs of 58 dependants.

It will be noted from the Accounts for 1939 that the financial position of the Fund has improved, and that there is now a surplus of income over expenditure. On the other hand, owing to the war the Electrical Engineers' Ball was not held in February last and the Fund will thereby suffer a loss of revenue in 1940 of between £200 and £250. This is causing the Committee of Management some anxiety, especially as it is expected that the demands on the Fund in this and coming years will be heavy owing to distress caused by the war. The Committee therefore appeal to those who normally attend the Ball to send a special donation of 5s. or 10s. to compensate in some way for this loss of revenue.

The Council earnestly hope that all members of The Institution will continue to give the Fund their active support. The Fund is able, under the provisions of the Finance Act 1922, to recover income tax on annual subscriptions, provided that the subscribing member signs a deed of covenant to give a fixed amount per annum for a minimum period of seven years. A number of contributors have agreed to subscribe under this arrangement, and if any other members wish to do so the Honorary Secretary of the Fund will be pleased to supply the necessary forms and particulars.

The Committee wish to express great appreciation to the Local Honorary Treasurers for their efforts in stimulating an active interest in the Fund among the members in the Local Centres, and their valuable assistance in the investigation of applications.

(53) THE INSTITUTION AND BODIES ON WHICH IT IS REPRESENTED

Appendix C (page 589) shows in diagrammatic form the organization of The Institution and the bodies on which it is represented.

APPENDIX A

Membership of The Institution

The changes in the membership since the 1st April, 1939, are shown in the following table:—

	Hon. Mem.	Mem.	Assoc. Mem.	Com.	Assoc.	Grad.	Stud.	Total
Totals at 1 April, 1939	12	2 106	7 344	102	1 374	4 780	3 326	19 044
Additions during the year:—								
Elected ..	1	4	166	3	66	263	1 103	1 606
Reinstated	—	1	8	—	1	4	5	19
Transferred to ..	—	96	417	—	5	419	—	937
Totals ..	1	101	591	3	72	686	1 108	2 562
Deductions during the year:—								
Deceased ..	3	46	43	1	3	17	12	125
Resigned ..	—	15	57	1	13	47	52	185
Lapsed ..	—	10	51	3	29	114	280	487
Transferred from ..	—	—	92	—	36	379	430	937
	3	71	243	5	81	557	774	1 734
Net Increase ..	..	..	..	..	..	..	..	828
Totals at 1 April, 1940	10	2 136	7 692	100	1 365	4 909	3 660	19 872

APPENDIX B

Meetings

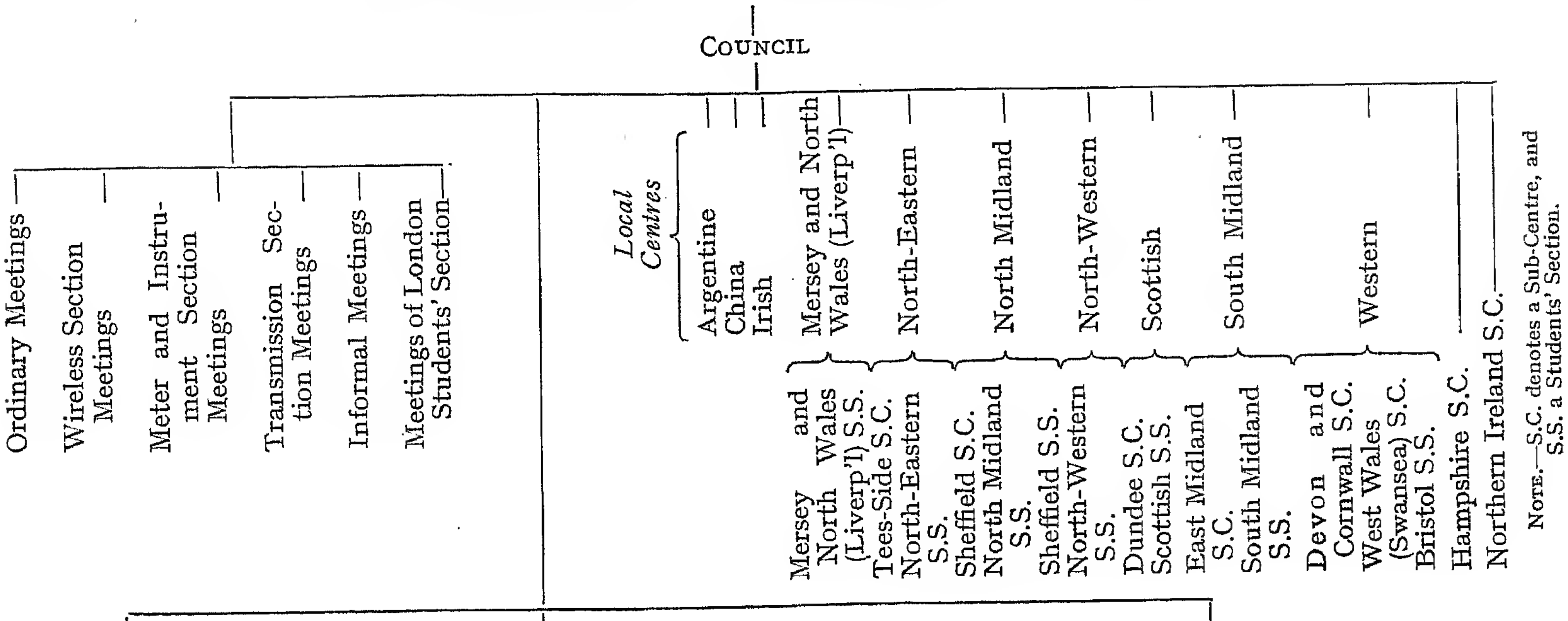
The following is a list of the meetings held during the past 12 months:—

Ordinary Meetings ..	10
Annual General Meeting	1
Annual General Meeting (Benevolent Fund) ..	1
Wireless Section ..	5
Meter and Instrument Section	5
Transmission Section ..	4
Informal Meetings ..	5
Council Meetings ..	14
Local Centres:	
Irish	5
Mersey and North Wales (Liverpool) ..	11
North-Eastern ..	7
North-Midland ..	7
North-Western ..	5
Scottish	5
South Midland ..	4
Western	5
Local Sub-Centres:	
Devon and Cornwall	1
Dundee	4
East Midland ..	3
Hampshire	2
Northern Ireland ..	9
Sheffield	5
Tees-Side	7
West Wales (Swansea)	2
Students' Sections:	
Bristol	8
Liverpool	10
London	5
North-Eastern ..	11
North Midland ..	6
North-Western ..	3
Scottish	5
Sheffield	8
South Midland ..	10

Committees:	
Benevolent Fund ..	9
Education and Examinations	6
Emergency	4
Finance (and Sub-Committee) ..	11
General Purposes (and Sub-Committees) ..	14
Informal Meetings ..	3
Membership	8
Meter and Instrument Section (and Sub-Committees) ..	13
National Certificates (England) ..	2
National Certificates (Scotland)	2
National Service ..	6
Overseas Activities ..	1
Papers (and Sub-Committees)	10
Scholarships ..	1
Science Abstracts ..	1
Ship Electrical Equipment Sub-Committee	1
Transmission Section (and Sub-Committees)	14
Wireless Section (and Sub-Committees) ..	16
Wiring Regulations (and Sub-Committees)	9
Other Committees ..	22
Total ..	346

APPENDIX C

THE INSTITUTION OF ELECTRICAL ENGINEERS



COMMITTEES OF COUNCIL

Education and Examinations
Finance
General Purposes
Library and Museum
Membership
Papers

SPECIAL COMMITTEES

Benevolent Fund
Earthing to Water Mains (Joint)
Electrical Engineers' Ball
Electricity (Supply) Regulations
Emergency
Faraday Medal and Honorary Membership Advisory
Home Security Advisory
Informal Meetings
International Relations
Local Centres
Meter and Instrument Section
Model General Conditions
National Service
Operating Theatres Electrical Apparatus
Overseas Activities
Patent Law
Scholarships
Science Abstracts
Ship Electrical Equipment Regulations
Transmission Section
Wireless Section
Wiring Regulations

Technical Committees
- Applications and Plant
- Education and Training
- Electricity in Mines
- Electrochemistry and Electrometallurgy
- Power Stations and their Equipment
- Radiological and Electromedical Apparatus
- Telegraphs and Telephones
- Traction, including Railways

Overseas Committees
- Ceylon
- India (Bombay, Calcutta, Lahore, and Madras)
- New South Wales
- Queensland
- South Australia
- Victoria and Tasmania
- Western Australia
- New Zealand
- Transvaal

BODIES ON WHICH THE INSTITUTION IS REPRESENTED

Bristol University
British Cast Iron Research Association
British Electrical and Allied Industries Research Association
British Electrical Development Association, Committee on Rural and Agricultural Electrification
British National Illumination Committee of the International Commission on Illumination
British Standards Institution
Building Industries National Council, Advisory Committee on Building Acts and Bye-laws
City and Guilds of London Institute
Council for the Preservation of Rural England
Electrical Association for Women
Engineering Joint Council
Engineering Joint Examination Board
Engineering Public Relations Committee
H.T. Conference, Paris, British National Committee [Body
Imperial College of Science and Technology, Governing
Imperial Minerals Resources Conference, Copper Committee
Institute of Industrial Administration, Examinations Advisory Council
Institute of Metals, Corrosion Research Committee
Institution of Civil Engineers, Engine and Boiler Testing Committee
Institution of Civil Engineers, Engineering Precautions (Air Raid) Committee Panel
International Association for Testing Materials
International Electrotechnical Commission, British National Committee
Joint Committee on Engineering Co-operation Overseas
Joint Committee on Materials and their Testing
Joint Committee of The Institution of Civil Engineers and the E.R.A. for Research on Earthing to Water Mains
Joint Fuel Committee
Loughborough Technical College, Advisory Committee
Manchester Regional Advisory Council for Technical and other forms of Further Education
Metalliferous Mining (Cornwall) School, Governing Body
Ministry of Labour, Central Register Advisory Council
National Certificates and Diplomas in Electrical Engineering, Joint Committees for
National Committee on Physics (Royal Society)
National Committee on Scientific Radio (Royal Society)
National Physical Laboratory, General Board
National Register of Electrical Installation Contractors
National Smoke Abatement Society
Professional Classes Aid Council
Royal Engineer Board
Science Museum, South Kensington, Advisory Council
Town Planning Institute, Committee on Overhead Transmission Lines

[*Continued at foot of column* 1.]

[*Continued from foot of next column.*]
Union of Lancashire and Cheshire Institutes, Panel for Engineering
University College, Nottingham, Electrical Engineering Advisory Committee
War Office Mechanization Board
Women's Engineering Society
World Power Conference, British National Committee

THE INSTITUTION OF ELECTRICAL ENGINEERS

REVENUE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1939.

Dr. EXPENDITURE.

Year ended 31 Dec., 1938. £ s. d.		£ s. d.	£ s. d.
	To MANAGEMENT:—		
	Salaries and Wages	17,812 17 4	
	Staff Provident Scheme	1,769 7 3	
	National Insurance	142 4 11	
	Audit Fee	120 15 0	
	Printing	1,156 9 4	
	Stationery and Office Requisites ..	735 15 5	
	Addressing Machine Requisites ..	57 14 2	
	Postage of Correspondence and Notices	1,200 8 7	
	Telephone	148 6 10	
22,045 16 3	Telephone Expenses	322 10 3	23,466 9 1
	,, INSTITUTION BUILDING:—		
	Ground Rent	2,201 0 0	
	Rates	3,321 6 10	
	Heating	1,206 18 11	
	Lighting and Power	484 2 6	
	Insurance	224 1 0	
	Transferred to Repairs Suspense Account	1,000 0 0	
	Household Requisites and Cleaning	663 18 1	
		9,101 7 4	
3,875 17 5	*Less* Rents from Tenants	5,525 0 0	3,576 7 4
	,, AIR RAID PRECAUTIONS:—		
	Headquarters	1,730 3 0	
nil	Weybridge	650 4 6	2,380 7 6
253 10 8	,, FURNITURE AND FITTINGS (Repairs and Renewals)		165 15 9
nil	,, CENTRAL REGISTER OF NATIONAL SERVICE ..		265 7 8
nil	,, HISTORY OF THE INSTITUTION		1,128 15 3
	,, JOURNAL:—		
	Printing	8,937 3 8	
	Postage	3,623 12 2	
	Wrappers and Envelopes	439 9 11	
		13,000 5 9	
8,933 7 9	*Less* Sales and Advertisements ..	3,699 10 11	9,300 14 10
115 19 6	,, PROCEEDINGS OF THE WIRELESS SECTION (Printing, Postage, etc.: *less* Sales)		175 10 3
613 19 7	,, STUDENTS' QUARTERLY JOURNAL (Editing, Printing, Postage, etc.: *less* Sales)		651 2 5
153 11 0	,, LENDING LIBRARY (Books, Printing, Postage, etc.)..		154 0 11
	,, SCIENCE ABSTRACTS:—		
	Abstracting, Editing, Printing, Postage, etc.	5,258 12 11	
940 10 11	*Less* Sales and Advertisements ..	4,664 8 5	594 4 6
	,, INSTITUTION MEETINGS:—		
	Advance Proofs	409 19 11	
	Reporting	122 6 6	
	Grant to London Students' Section	24 2 3	
	Honorarium to Kelvin Lecturer ..	25 0 0	
	Refreshments, Assistance, etc. ..	297 7 10	
	Travelling Expenses of Authors of Papers	50 13 11	
	Overseas Meetings	189 7 11	
1,580 15 9	Loud-Speaker Installation	266 0 0	1,384 18 4
	Carried Forward		£43,243 13 10

INCOME. Cr.

Year ended 31 Dec., 1938. £ s. d.		£ s. d.	£ s. d.
46,821 13 2	By SUBSCRIPTIONS		48,051 16 9
1,451 2 0	,, ENTRANCE FEES		1,466 17 0
751 3 2	,, MEMBERS' SUBSCRIPTIONS TO "SCIENCE ABSTRACTS"		766 10 6
6,167 3 8	,, DIVIDENDS AND INTEREST		6,074 16 1
251 8 8	,, SALES OF "MODEL GENERAL CONDITIONS" ..		188 8 11
123 18 9	,, SALES OF "WIRING REGULATIONS"		164 8 9
7 12 10	,, SALES OF "SHIP WIRING REGULATIONS" (*see contra*)		48 11 4
	,, EXAMINATIONS:—		
	Graduateship Examination (Candidates' Fees and Sale of Papers, *less* Examiners' Fees, Printing, etc.)..	691 12 4	
1,462 12 3	National Certificates and Diplomas (Candidates' and School Authorities' Fees, *less* Assessors' Fees, Stationery, Postage, Travelling Expenses, etc.)	882 2 3	1,573 14 7
	Carried Forward ..		£58,335 3 11

REVENUE ACCOUNT—*continued.*

Dr. EXPENDITURE—*continued.*

		£ s. d.	£ s. d.
	Brought Forward		.. 43,243 13 10
	To Local Centres:—		
	Money Grants	4,180 14 11	
	Travelling Expenses	669 19 8	
	Faraday Lectures	329 12 1	
	Students' Lectures	67 15 5	
5,563 14 10			5,248 2 1
304 10 11	,, Premiums for Papers		325 11 9
	,, Scholarships:—		
	Ferranti Scholarship	312 10 0	
	Duddell Scholarship	450 0 0	
	Silvanus Thompson Scholarship ..	226 3 0	
	Contribution to Salomons Scholarship	41 7 6	
	Contribution to David Hughes Scholarship	39 7 10	
1,025 4 5			1,069 8 4
	,, Special Grants:—		
	British Standards Institution ..	750 0 0	
	Electrical Research Association ..	750 0 0	
	National Illumination Committee ..	32 0 0	
	International Conference on High Tension Systems	32 0 7	
	Engineering Public Relations Committee	2 2 0	
	World Power Conference	25 0 0	
	Joint Committee on Materials and their Testing	10 0 0	
	"Earthing to Water Mains" Joint Committee	50 0 0	
	Building Industries National Council	25 0 0	
	Engineering Joint Examinations Board	25 0 0	
2,840 14 2			1,701 2 7
nil	,, Ship Wiring Regulations (Cost of printing new edition) (*see contra*)		210 17 7
121 19 9	,, Annual Dinner		107 17 11
711 19 7	,, Conversaziones		717 9 8
49 8 3	,, Legal Expenses		250 15 6
181 10 0	,, Miscellaneous Expenses		121 2 4
378 19 5	,, Loss on Exchange on Overseas Deposits remitted to London ..		876 15 11
49,691 10 2			53,872 17 6
277 12 2	,, Amount Transferred to Sinking Fund (Premiums for Redemption of Cost of Building and Lease) ..	277 12 2	
7,067 12 2	,, **Balance carried to Balance Sheet** ..	4,184 14 3	
7,345 4 4			4,462 6 5
57,036 14 6			£58,335 3 11

INCOME—*continued.* **Cr.**

		£ s. d.
	Brought Forward	.. 58,335 3 11
57,036 14 6		£58,335 3 11

BALANCE SHEET, 31st DECEMBER, 1939.

Dr. LIABILITIES.

	£	s.	d.	£	s.	d.
To Uninvested Balances of Trust Funds				479	1	2
,, Sundry Creditors				9,227	13	2
,, Subscriptions received in advance				1,138	8	9
,, Repairs Suspense Account:—						
Balance at 1st January, 1939	4,441	6	7			
Amount set aside in 1939	1,000	0	0			
	5,441	6	7			
Less Expenditure on Repairs in 1939	1,422	17	2			
				4,018	9	5
Carried Forward				£14,863	12	6

ASSETS. **Cr.**

	£	s.	d.	£	s.	d.
By Institution Building and Lease:—						
Cost	73,028	6	10			
Less Reserve for Depreciation, being Surrender Values of Sinking Fund Policies	12,095	8	0			
				60,932	18	10
,, Sinking Fund (Surrender Values of Policies for Redemption of Cost of Building and Lease)				12,095	8	0
,, Library (exclusive of the Ronalds Library and Faraday Papers, which are held in trust):—						
As per last Balance Sheet	2,035	0	3			
Additions in 1939	165	11	3			
	2,200	11	6			
Less Depreciation (10 %)	220	1	2			
				1,980	10	4
,, Thompson Memorial Library (Contribution towards purchase)				1,000	0	0
,, Furniture, Fittings, and Apparatus:—						
As per last Balance Sheet	3,028	18	8			
Less Depreciation (5 %)	151	8	11			
				2,877	9	9
,, Sundry Debtors				2,892	3	2
,, Insurance Premiums and Sundry Payments in Advance				940	17	7
,, Stock of Paper, etc., for Publications				2,091	14	2
,, Investments (at or under cost):—						
£2,600 Natal Zululand Railways 3 % Debenture Stock	2,270	12	0			
£1,500 London, Midland and Scottish Railway 4 % Preference Stock	1,513	10	4			
£2,000 Assam Bengal Railways 3 % Stock (1931 or after)	1,548	0	6			
£750 Western Australia 4 % Stock (1942–62)	730	8	3			
£750 Union of South Africa 4 % Stock (1943–63)	742	12	0			
£35 East Indian Railway "B" Annuity (1953)	791	5	4			
£1,500 South Australia 4 % Stock (1940–60)	1,494	10	6			
£6,450 3½ % War Stock	6,306	9	0			
£19,375 4 % Funding Loan (1960–90)	15,500	0	0			
£8,700 3½ % Conversion Stock (1961 or after)	6,651	3	3			
£11,970 11s. 4 % Consolidated Stock	10,291	6	6			
£1,000 London, Midland and Scottish Railway 5 % Preference Stock (1955)	1,020	4	6			
Carried Forward	£48,860	2	2	£84,811	1	10

BALANCE SHEET—*continued.*

BALANCE SHEET—*continued.*

Dr. LIABILITIES—*continued.*

			£ s. d.	£ s. d.
Brought Forward				14,863 12 6
To Surplus of Assets over Liabilities:—				
Balance at 1st January, 1939			220,288 7	
Excess of Income over Expenditure for 1939 brought forward from Revenue Account		£4,184 14 3		
Less Allocation to Supplementary Superannuation Account ..	£750 0 0			
Depreciation:—				
Library (*per contra*)	220 1 2			
Furniture, Fittings, and Apparatus (*per contra*)	151 8 11			
		1,121 10 1		
			3,063 4 2	
				223,351 11 8
				£238,315 4 2

W. McCLELLAND,
Honorary Treasurer.

W. K. BRASHER,
Secretary.

ASSETS—*continued.* **Cr.**

	£ s. d.	£ s. d.
Brought Forward		84,811 1 10
By INVESTMENTS (at or under cost)—*contd.*		
Brought forward	48,860 2 2	
£4,400 North Metropolitan Power Station 5 % Guaranteed Debenture Stock (1957)	4,388 11 0	
£2,000 London, Midland and Scottish Railway 5 % Redeemable Debenture Stock (1952)	1,982 5 9	
£2,300 East Indian Railway 4½ % Irredeemable Debenture Stock	2,019 13 0	
£5,000 Commonwealth of Australia 5 % Stock (1945–75)	4,964 17 6	
£2,000 Tynemouth Corporation 5% Stock (1947–57)	2,025 4 0	
£2,500 Stoke-on-Trent Corporation 5 % Stock (1948–68)	2,550 6 0	
£3,500 East Indian Railway 3½ % Debenture Stock (1937)	2,475 15 6	
£5,000 Brighton Corporation 4¾% Stock (1945–75)	5,050 8 0	
£2,000 New South Wales 5¼ % Stock (1947–57) ..	2,013 19 0	
£2,600 Kenya Government 4½ % Stock (1950) ..	2,483 4 0	
£3,000 Southern Railway 4 % Debenture Stock ..	2,520 5 0	
£2,500 Corporation of London 4½ % Debenture Stock (1940–85)	2,462 14 0	
£3,000 Birmingham Corporation 4½ % Stock (1948–68)	2,906 11 0	
£3,000 London County 4½ % Stock (1945–85) ...	2,936 11 0	
£1,000 Bootle Corporation 4¾ % Stock (1949–59)	967 12 0	
£11,722 17s. 11d. 2¾ % Funding Loan (1952–57) ..	9,888 5 10	
£2,000 Southampton Corporation 5 % Stock (1947–67)	2,027 14 0	
£4,881 London Passenger Transport Board 4½ % "A" Stock (1985–2023)	4,440 2 9	
£2,000 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)	2,080 11 0	
£2,400 Ayr County Council 5 % Stock (1947–57)	2,484 4 0	
£2,400 Union of South Africa 5 % Stock (1950–70)	2,436 4 0	
£1,000 Nyasaland Government 4½ % Guaranteed Stock (1952–72)	1,142 13 0	
£2,500 London Passenger Transport Board 5 % "B" Stock (1965–2023)	3,017 1 0	
£5,000 London County 2¾ % Consolidated Stock (1960–70)	4,811 2 6	
£5,600 3 % Funding Loan (1959–69)	5,419 19 0	
£3,000 Birmingham Corporation 3¼ % Stock (1957–62)	2,953 8 6	
£2,000 3 % Redemption Loan (1986–96)	1,842 14 0	
£5,600 Ipswich Corporation 3¼ % Stock (1964) ..	5,302 10 0	
£2,200 Manchester Corporation 3 % Stock (1958–63)	2,013 4 0	
(*Marketvalue 31st December*, 1939, £149,516 4s. 8d.) ..		140,467 12 6
„ CASH AT BANKS IN AUSTRALIA AND NEW ZEALAND		6,885 16 11
(*Sterling equivalent 31st December*, 1939, £5,500 5s. 5d.)		
„ CASH IN HANDS OF LOCAL CENTRES ON 30 SEPT., 1939 ..		1,346 19 2
„ CASH:—		
At Bank	4,357 7 10	
In hands of Secretary	346 5 11	
		4,703 13 9
		£238,215 4 2

We beg to report that we have audited the Balance Sheet of The Institution of Electrical Engineers, dated 31st December, 1939, and above set forth, together with the annexed Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of The Institution's affairs according to the best of our information and the explanations given to us and as shown by the books of The Institution.

ALLEN, ATTFIELD & CO., Auditors,
Chartered Accountants,
24, MARTIN LANE, CANNON STREET, E.C.4.

15*th April*, 1940.

SALOMONS SCHOLARSHIP TRUST FUND (Capital).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount (as per last Account)	2,085 1 4	By Investments (at cost):—	
		£1,600 13s. 3d. Commonwealth of Australia 3 % Stock (1955–58)	1,585 1 4
		£500 Cardiff Corporation 3 % Stock (1952–55)	500 0 0
	£2,085 1 4		£2,085 1 4

SALOMONS SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1939	100 0 0	By Dividends received in 1939	58 12 6
		„ Contribution from Institution	41 7 6
	£100 0 0		£100 0 0

DAVID HUGHES SCHOLARSHIP TRUST FUND (Capital).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount (as per last Account)	2,000 0 0	By Investment (at cost):—	
		£2,045 Metropolitan Water Board (Staines Reservoirs) 3 % Guaranteed Debenture Stock (1922 or after)	1,998 15 0
		„ Balance carried to Balance Sheet*	1 5 0
	£2,000 0 0		£2,000 0 0

DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1939	100 0 0	By Dividends received in 1939	60 11 8
		„ Interest received in 1939	0 0 6
		„ Contribution from Institution	39 7 10
	£100 0 0		£100 0 0

PAUL SCHOLARSHIP FUND (Capital).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount (as per last Account)	1,000 0 0	By Investments (at cost):—	
		£625 4 % Funding Loan (1960–90)	500 0 0
		£518 3s. 8d. Central Electricity Board 5 % Debenture Stock (1950–70)	500 0 0
	£1,000 0 0		£1,000 0 0

PAUL SCHOLARSHIP FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1939	50 0 0	By Balance (as per last Account)	21 10 0
„ Balance carried to Balance Sheet* ..	22 1 9	„ Dividends received in 1939	50 11 9
	£72 1 9		£72 1 9

* Included in the total of £479 1s. 2d. shown on the Liabilities side of the Balance Sheet.

WILDE BENEVOLENT TRUST FUND (Capital).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount (as per last Account)	3,049 16 2	By Investments (at cost):—	
		£1,308 London and North Eastern Railway 4 % First Guaranteed Stock	1,744 3 11
		£100 London County 2¾ % Consolidated Stock (1960–70)	101 8 6
		£250 New South Wales 4 % Stock (1942–62)	251 6 0
		£500 3½ % War Stock	501 9 3
		£381 15s. 1d. 4 % Funding Loan (1960–90)	300 0 0
		£200 3½ % Conversion Stock (1961 or after)	151 8 6
	£3,049 16 2		£3,049 16 2

WILDE BENEVOLENT TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Grants made in 1939	104 0 0	By Balance (as per last Account)	91 9 9
,, Balance carried to Balance Sheet*	92 3 6	,, Dividends received in 1939	104 1 1
		,, Interest received in 1939	0 12 8
	£196 3 6		£196 3 6

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Capital).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount (as per last Account)	1,700 0 0	By Investment (at cost):—	
		£2,000 3½ % War Stock	1,700 0 0
	£1,700 0 0		£1,700 0 0

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Grants made in 1939	81 5 0	By Balance (as per last Account)	72 10 0
,, Balance carried to Balance Sheet*	61 5 0	,, Dividends received in 1939	70 0 0
	£142 10 0		£142 10 0

PAGE PRIZE FUND (Capital).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount (as per last Account)	100 19 5	By Investments (at cost):—	
		£50 3½ % War Stock	50 19 5
		£51 16s. 4d. Central Electricity Board 5 % Debenture Stock (1950–70)	50 0 0
	£100 19 5		£100 19 5

PAGE PRIZE FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Cost of Prize awarded in 1939	4 18 7	By Balance (as per last Account)	9 6 1
,, Balance carried to Balance Sheet* ..	8 13 8	,, Dividends received in 1939	4 6 2
	£13 12 3		£13 12 3

THORROWGOOD SCHOLARSHIP TRUST FUND (Capital).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount (as per last Account)	1,000 0 0	By Investment (at cost):—	
		£1,005 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)	1,000 0 0
	£1,000 0 0		£1,000 0 0

* Included in the total of £479 1s. 2d. shown on the Liabilities side of the Balance Sheet.

THORROWGOOD SCHOLARSHIP TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1939	40	12	6	By Balance (as per last Account)	51	6	3
,, Balance carried to Balance Sheet	60	6	2	,, Dividends received in 1939	49	12	5
	£100	18	8		£100	18	8

SWAN MEMORIAL SCHOLARSHIP FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last account)	2,968	12	4	By Investments (at cost):—			
				£1,000 Sunderland Corporation 5 % Stock (1946–56)	1,116	13	0
				£640 Sunderland Corporation 5 % Stock (1950–60)	728	8	0
				£1,135 17s. 9d. 3½ % Conversion Stock (1961 or after)	1,123	11	4
	£2,968	12	4		£2,968	12	4

SWAN MEMORIAL SCHOLARSHIP FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1939	120	0	0	By Balance (as per last Account)	9	1	8
,, Balance carried to Balance Sheet*	9	6	3	,, Dividends received in 1939	120	4	7
	£129	6	3		£129	6	3

WILLIAM BEEDIE ESSON SCHOLARSHIP TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	3,006	2	6	By Investments (at cost):—			
				£1,500 3½ % War Stock	1,603	2	6
				£200 New Zealand 5 % Stock (1949)	233	0	0
				£250 St. Helens Corporation 5 % Stock (1950–70)	293	15	0
				£250 Sunderland Corporation 5 % Stock (1950–60)	293	15	0
				£250 Birmingham Corporation 5 % Stock (1946–56)	291	5	0
				£250 Grimsby Corporation 5 % Stock (1950–60)	291	5	0
	£3,006	2	6		£3,006	2	6

WILLIAM BEEDIE ESSON SCHOLARSHIP TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholar in 1939	44	0	0	By Balance (as per last Account)	156	17	5
,, Balance carried to Balance Sheet*	223	19	10	,, Dividends received in 1939	111	2	5
	£267	19	10		£267	19	10

* Included in the total of £479 1s. 2d. shown on the Liabilities side of the Balance Sheet.

Plate 1

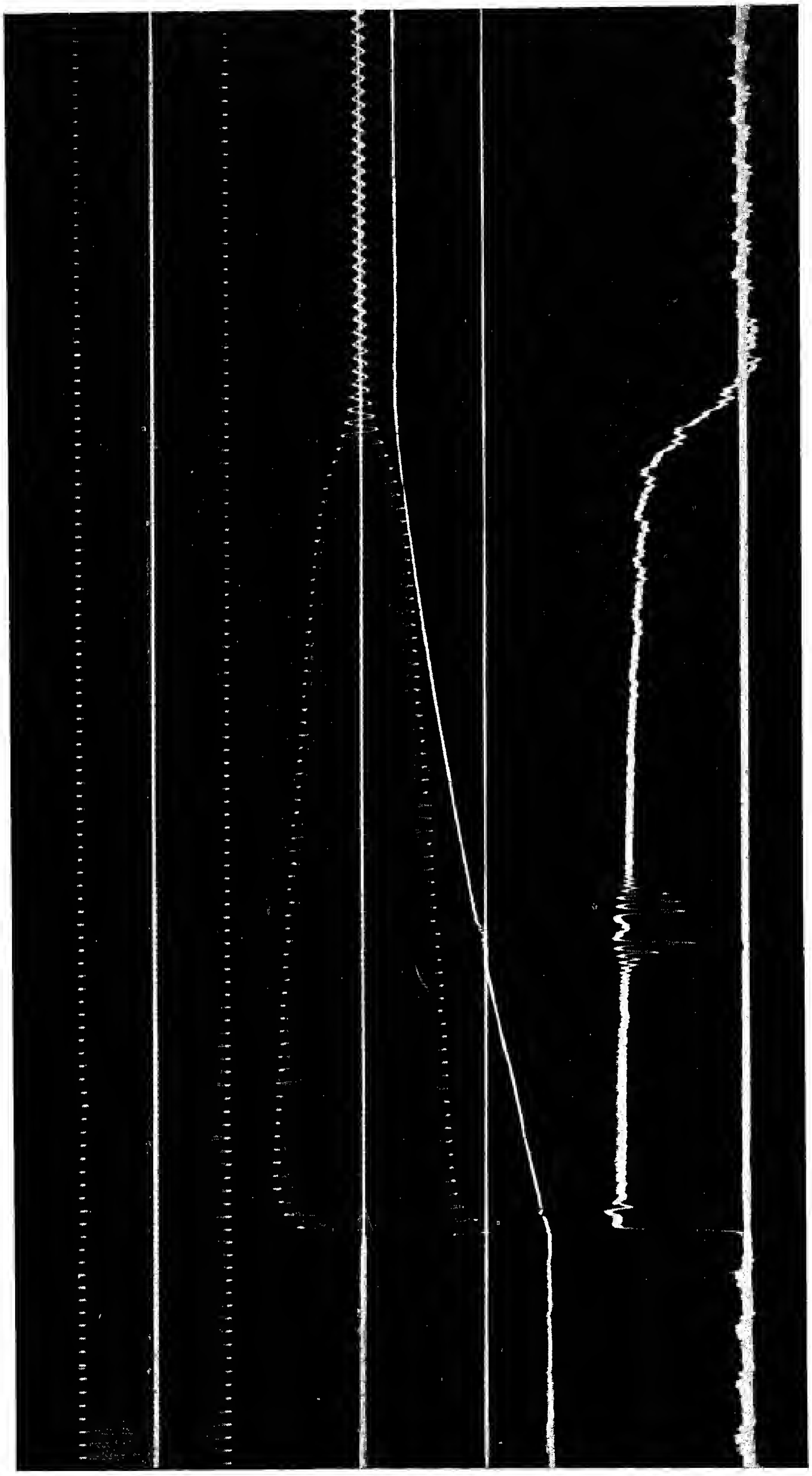


Fig. 3.—Oscillograms of line voltage, line current, speed and acceleration of the double squirrel-cage motor during reversal on 420 volts.

Plate 2

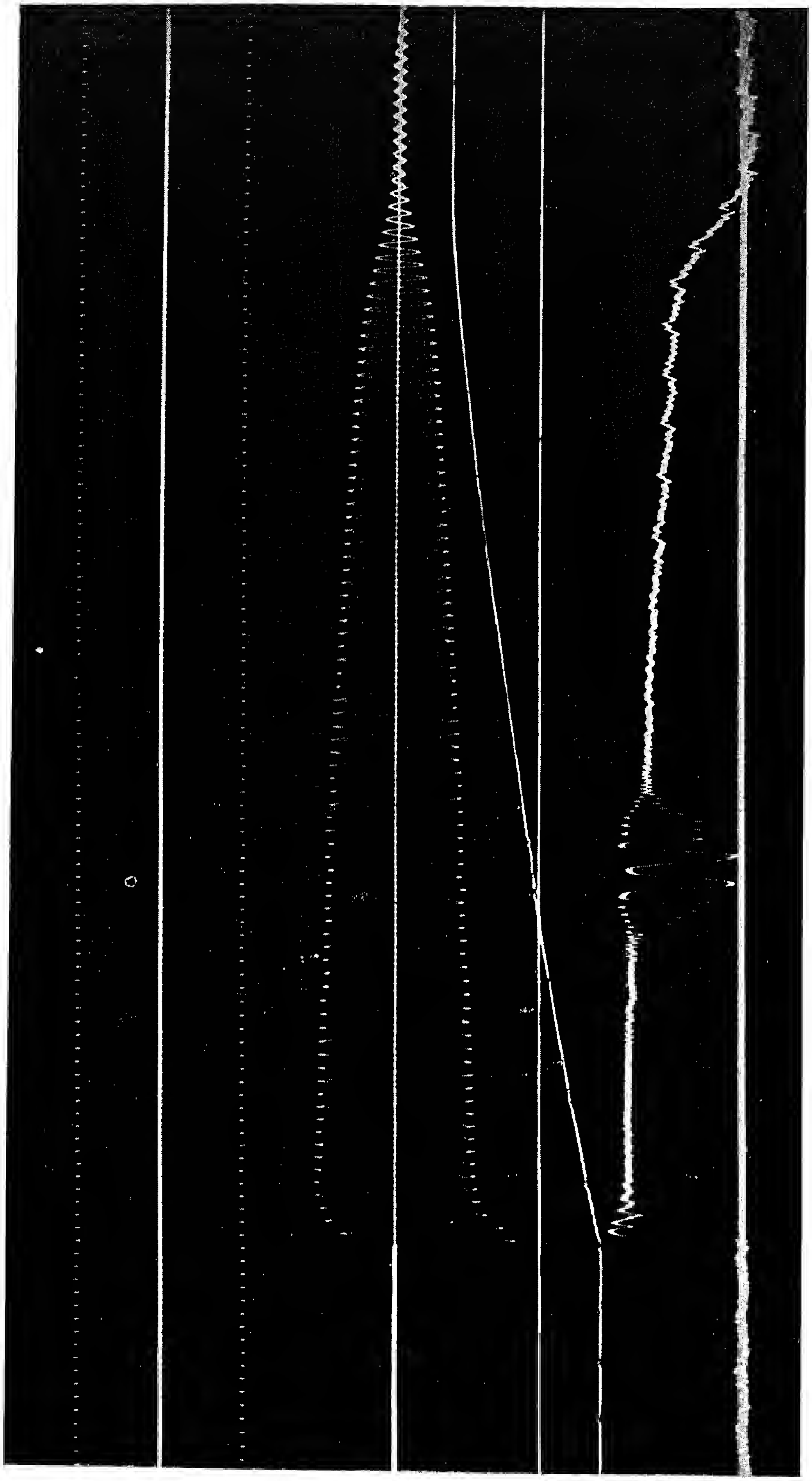


Fig. 4.—Oscillograms of line voltage, line current, speed and acceleration of the double squirrel-cage motor during reversal on 380 volts.

Plate 3

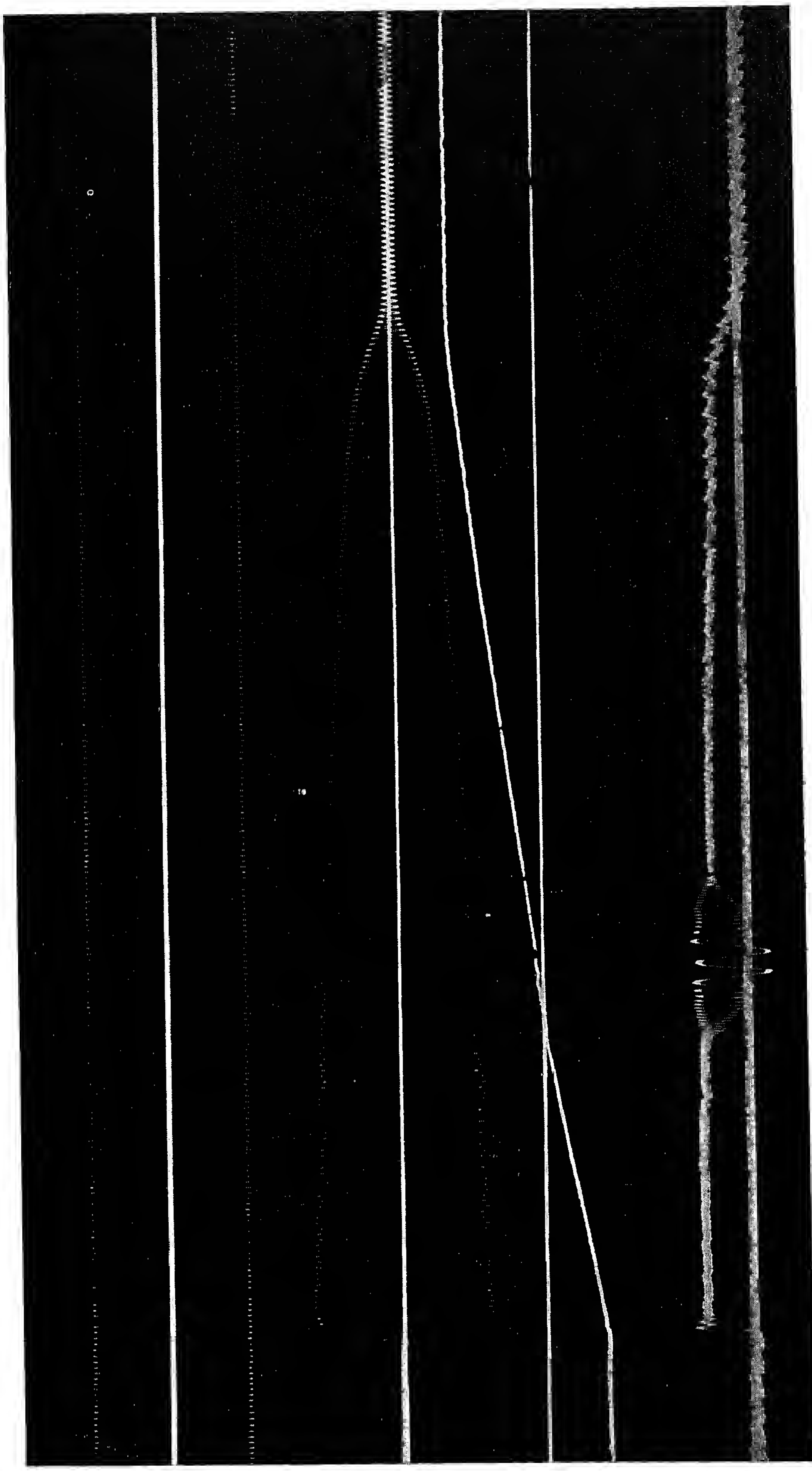


Fig. 5.—Oscillograms of line voltage, line current, speed and acceleration of the double squirrel-cage motor during reversal on 270 volts.

Plate 4

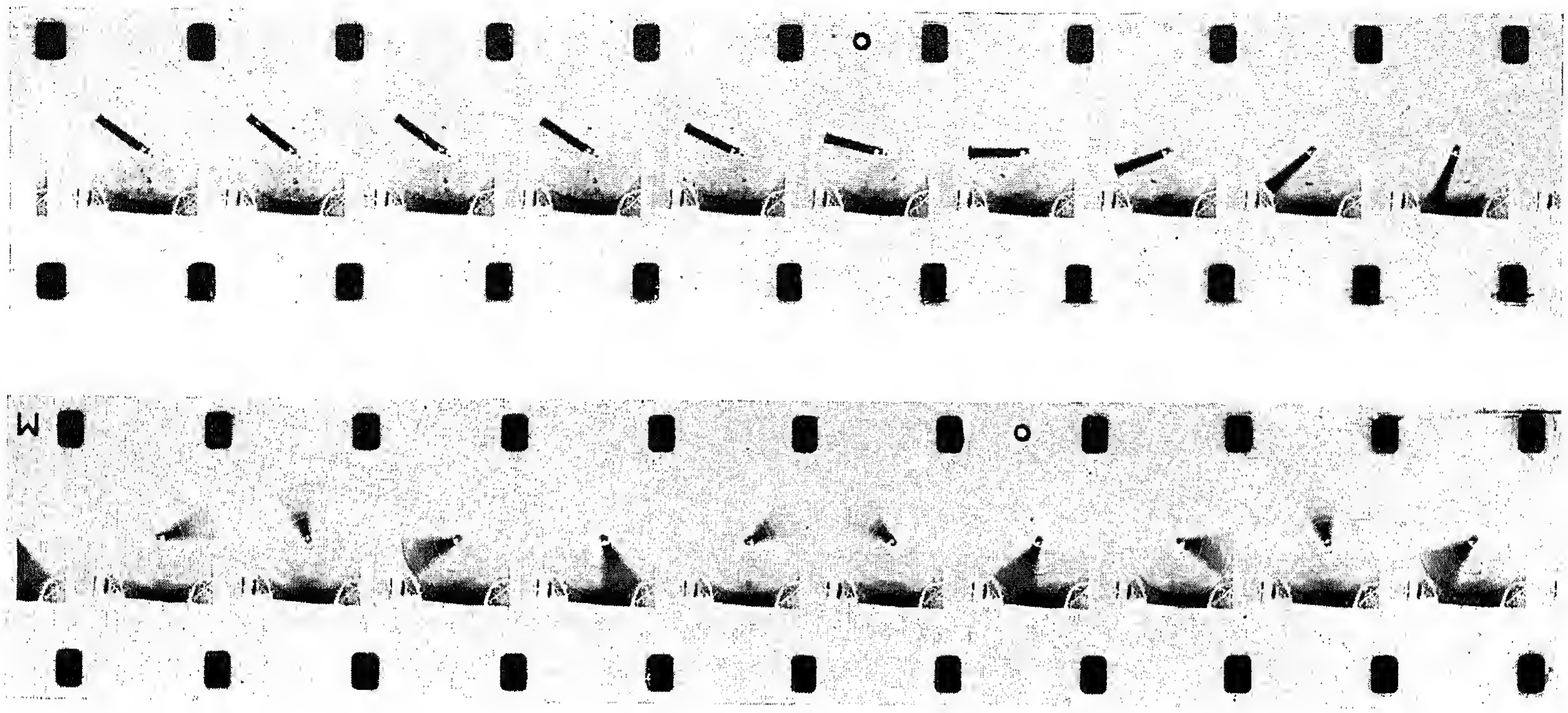


Fig. 7.—Example of parts of a record taken with the Ensign motion picture camera, showing the double squirrel-cage motor accelerating from rest.

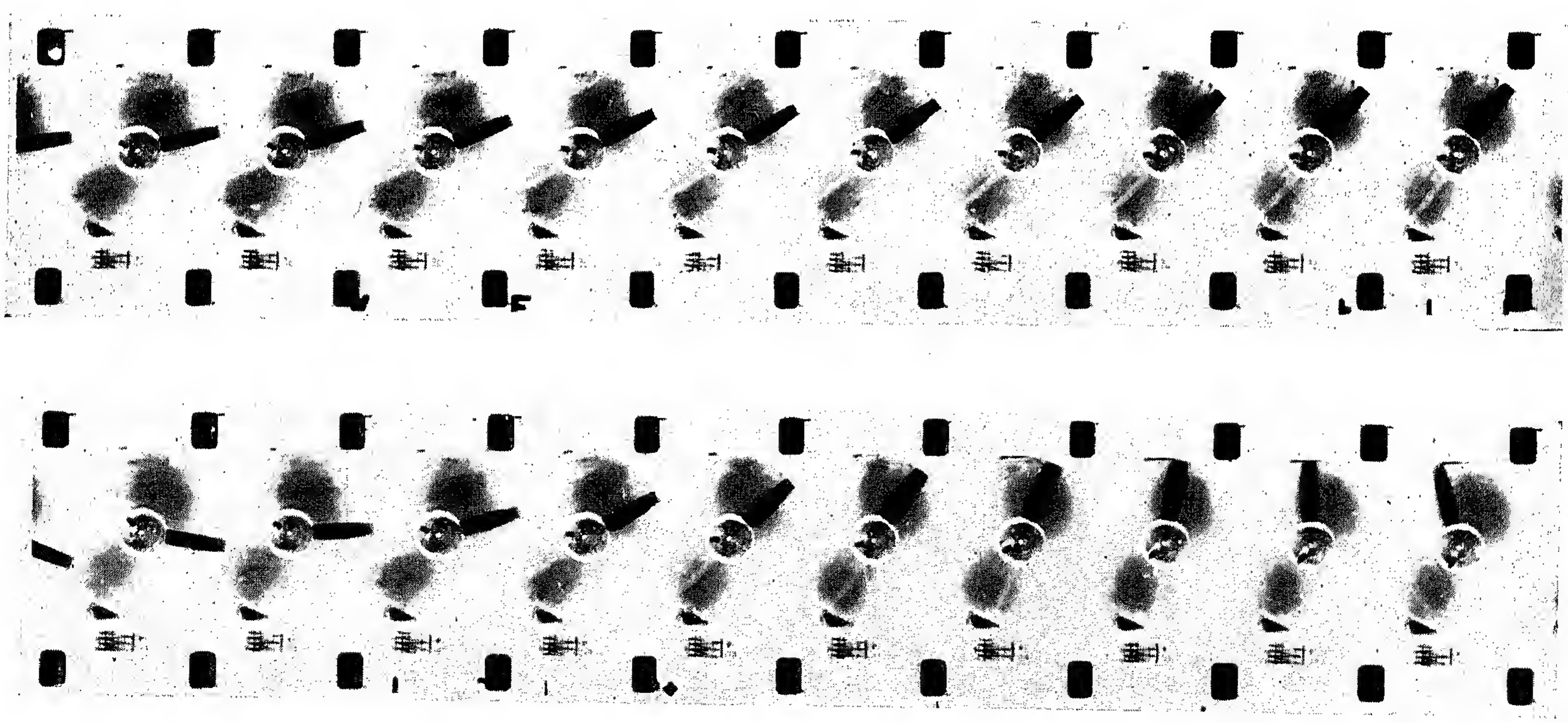


Fig. 10.—Example of parts of a record taken with the Western Electric high-speed camera. The vernier clock-time images appear in the corner of each frame.

METHODS OF MEASURING THE TORQUE OF INDUCTION MOTORS*

By A. C. W. VINCENT CLARKE, B.Sc., Ph.D., Graduate.†

(*Paper first received* 13*th June, and in final form* 17*th November*, 1939.)

SUMMARY

The problem of measuring torque in induction motors is discussed, and methods of measurement are described based on the analysis of motion-picture records.

(1) INTRODUCTION

It is characteristic of the squirrel-cage induction motor that, for the same applied stator voltage, it develops a definite torque at any particular given speed. Most features of the behaviour of such a motor are therefore best understood from the characteristic curve of torque plotted against speed, and it follows that the measurement of torque is of great importance in any investigation concerning these machines.

The purpose of this paper is to discuss some of the methods of torque measurement applicable to squirrel-cage motors, in the light of experiments made by the author during the course of research on this type of motor. The methods which will be considered are: (i) Loading by means of a water-cooled brake drum. (ii) The use of a rotational accelerometer. (iii) The use of a simple form of motion-picture camera. (iv) The use of a high-speed camera.

In the first of these methods the measurements are made with the motor under test running at a uniform speed. In the remaining three types of test, measurements are made "instantaneously" while the speed of the motor is changing. The distinction is an important one.

(2) THE TORQUE/SPEED CHARACTERISTIC

The curve of torque against speed may be considered from rest (zero speed or 100 per cent slip) up to the speed at which the motor runs unloaded, which for a normal motor approximates to the synchronous speed (zero slip). In certain cases, as, for example, in lift motors, the curve may be considered to extend beyond this range. *Hypersynchronous* speeds are those at which the motor is driven above its synchronous speed, exerting a resisting torque in a sense opposite to that of the torque normally developed. At such speeds the slip is negative. *Negative* speeds are those at which the motor is driven backwards, and acts as a brake. At such speeds the slip is greater than 100 per cent.

(3) LOADING BY MEANS OF A BRAKE DRUM

The measurement of torque by means of a water-cooled brake drum and hanging weights is so commonly carried out that the method needs no description. It will be enough to point out its advantages and disadvantages when used for an induction motor.

The results obtainable are of a high order of accuracy,

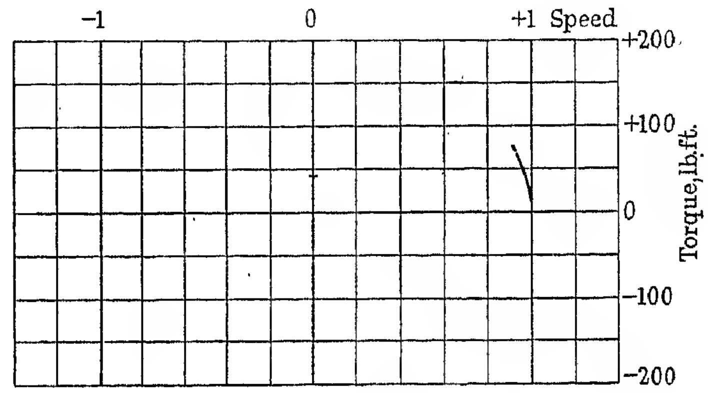


Fig. 1.—Torque from brake loading tests: single squirrel-cage machine, 50 c./s., 400 volts (line).

but the range of speeds over which observations may be made is extremely limited, being confined almost entirely to the speeds between that at the highest allowable overload and that at no load. Even if a d.c. generator is substituted for the brake drum as a load the range of observation is only extended to a limited amount into the hypersynchronous region.

An increase in the range of speeds over which observations may be made with the motor running uniformly might be obtained if the voltage applied to the stator

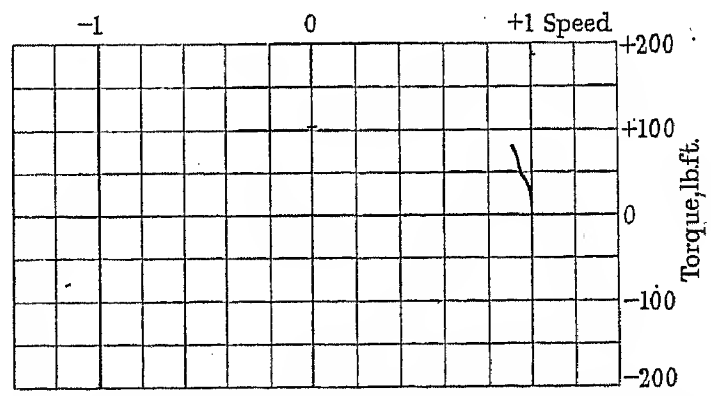


Fig. 2.—Torque from brake loading tests: double squirrel-cage machine, 50 c./s., 400 volts (line).

were reduced below that for which the motor was designed. This procedure, however, is inadmissible, as experiments to be described in Section (4) show that no simple correction can be relied upon to refer results obtained at reduced voltage to those which would be obtained at normal voltage.

Figs. 1 and 2 show curves of torque against speed obtained by brake loading for a 7-h.p. single-cage motor

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

† University of London, King's College.

The work described in this paper was carried out during the author's tenure of the Swan Memorial Scholarship.

and for a 7-h.p. double-cage, or "high torque," motor. The curves are plotted to a standard scale (synchronous speed = 1) for comparison with those obtained by other methods, and the limited range of the speeds which they cover is apparent.

(4) USE OF A ROTATIONAL ACCELEROMETER

Measurements of torque made while a motor is in actual course of acceleration, against the control of its own inertia (which may be increased by a flywheel), cover the whole range of speeds from zero (100 per cent slip) to light running speed (nearly zero slip), and may even be extended into the regions of hypersynchronous and negative speeds. Such measurements have the advantage that they can be made to show the behaviour of the motor during the period of its acceleration from rest up to a working speed, but they are attended by technical difficulties and considerable expense, and generally give results of less accuracy than those obtained with the motor under test running at a uniform speed.

The rotational accelerometer (described in the *Metropolitan-Vickers Gazette*, October, 1931, p. 82) has been in use for a number of years. The principle of its operation is simple, but it is so costly and of such

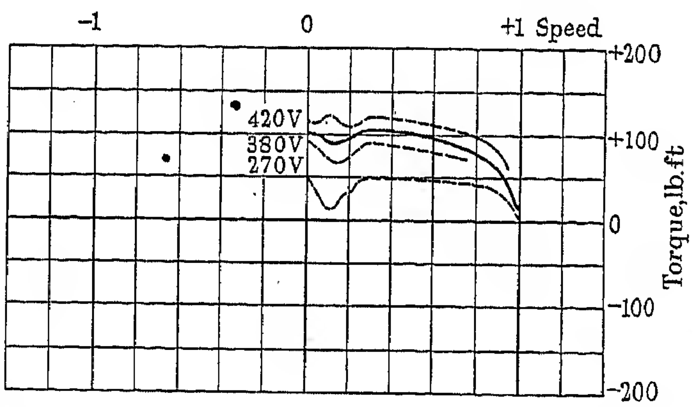


Fig. 6.—Torque from rotational accelerometer: double squirrel-cage machine, 50 c./s., 400 volts (line).

specialized construction as to be, as far as is known to the author, unique in this country.

A homopolar generator is coupled to the motor under test and develops a smooth e.m.f. proportional to the speed of the motor. This is applied across a non-inductive resistance to give an oscillogram of speed. At the same time an oscillogram of acceleration is obtained by applying the homopolar e.m.f. to a specially designed amplifier, which differentiates with respect to time by means of pure capacitance coupling. A curve of acceleration against speed may thus be derived, and with a knowledge of the moments of inertia involved the values of acceleration are convertible to values of torque.

Fig. 3 (see Plate 1, facing page 596), Fig. 4 (Plate 2) and Fig. 5 (Plate 3) show oscillograms obtained in this way for the double-cage motor at three different voltages (420 V, 380 V and 270 V). To eliminate disturbances due to switching on the apparatus, the curves are started from a condition where the motor is running freely by inertia in a direction opposite to that in which it will be driven by the voltage applied. This ensures that the results in the neighbourhood of zero speed are not obscured. Oscillograms are thus obtained from a negative speed to no-load speed, showing, against a base of time, (i) applied stator voltage, (ii) stator current, (iii) speed, (iv) acceleration.

Fig. 6 shows the curves, derived from the oscillograms, of torque against speed, and these confirm the statement in the preceding Section that no simple correction can refer results obtained at reduced voltage to those obtained at normal voltage. The curve for 400 volts, the normal working voltage of the motor, is interpolated and drawn as a full line.

(5) USE OF A SIMPLE FORM OF MOTION PICTURE CAMERA

In an attempt to find a less expensive method than the preceding one, experiments were made in measuring torque by means of a motion picture camera.

Assuming that the camera takes pictures at equal intervals of time, the displacement of the rotor under test during the interval between two successive exposures is a measure of its speed of rotation. The values of speed obtained in this way can be plotted against time, and differentiated to give values of acceleration. The pictures are obtained by photographing a disc attached to the rotor of the motor under test, carrying a white radial line on a matt black ground. Their appearance is

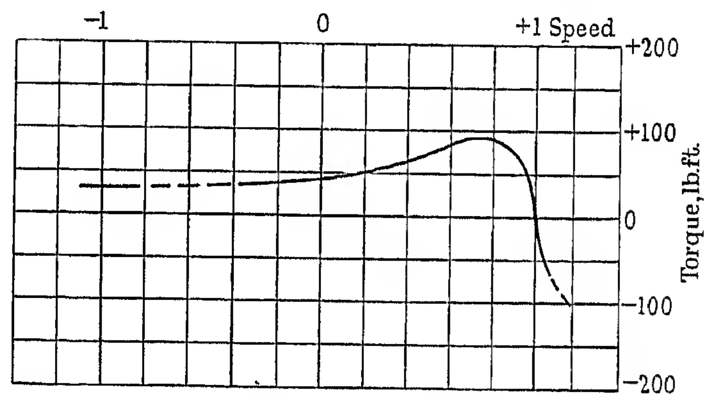


Fig. 8.—Torque by motion-picture method: single squirrel-cage machine, 50 c./s., 400 volts (line).

shown in Fig. 7 (Plate 4), and torque/speed curves derived by this method are shown in Figs. 8 and 9, referring respectively to the single-cage and the double-cage motors.

The results tend to lose accuracy as the higher speeds are approached, owing to the limited rate at which the camera takes pictures. In these tests the synchronous speeds of the two (6-pole) motors were both 1 000 r.p.m., and the speed of 60 pictures per second was the highest at which the camera could operate; great precautions had to be observed to assure that the rate of taking pictures was uniform. It will be seen from Fig. 7 that at the higher speeds of the disc the radial line appears as a sector, owing to the finite time of exposure.

The camera used was a mechanically (clockwork) driven model made by the Ensign Company, using 16-mm. film. As a result of tests it was found important to rewind it before each take, and to allow 2–3 sec. between the starting of the camera and the beginning of the operations to be photographed. Takes were best made in succession, as the camera was found to run less smoothly after a period of storage.

Of a number of methods tried for measuring the angular position of the radial line in each picture,

including the use of a projector and screen, the most successful was to lay the film on a raised sheet of glass and, with a transparent protractor, to measure the angular position of the line with reference to the film edge. The angular displacements of the radial line between each

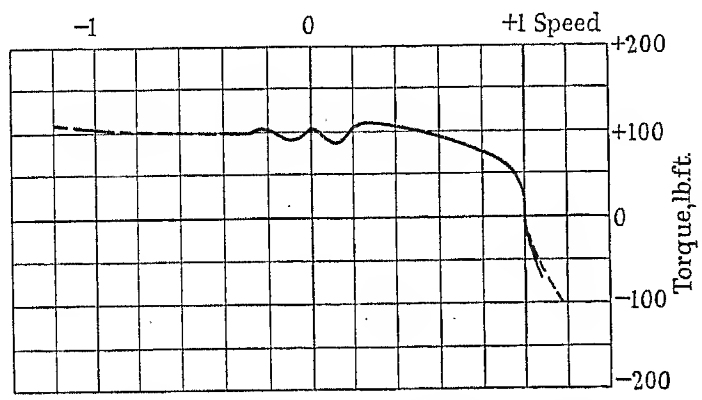


Fig. 9.—Torque by motion-picture method: double squirrel-cage machine, 50 c./s., 400 volts (line).

picture and the next were plotted on a base of time and, from a knowledge of the rate of taking, these were converted to units of speed and differentiated to give acceleration. Hence, the moment of inertia of the rotor under test and its associated masses being known, the torque/speed curves of Figs. 8 and 9 could be derived.

(6) USE OF A HIGH-SPEED MOTION-PICTURE CAMERA

The limitations of the motion-picture camera method just described are the great care which is necessary to keep the rate of taking uniform, the difficulty of obtaining a high enough rate to photograph satisfactorily speeds in the neighbourhood of 1 000 r.p.m., and the consequent inaccuracy of torque measurements made at these speeds.

These limitations are largely overcome by the Western Electric Co.'s high-speed camera, which is electrically driven and provides for taking rates up to 2 400 pictures

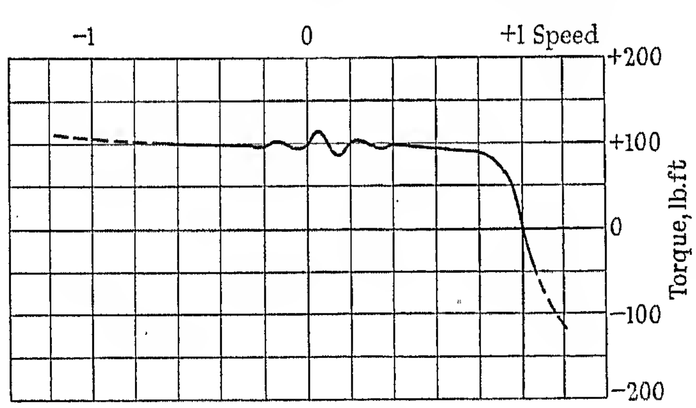


Fig. 11.—Torque from high-speed camera tests: double squirrel-cage machine, 50 c./s., 400 volts (line).

per second on 16-mm. film. Pictures taken at about 450 per second are shown in Fig. 10 (Plate 4), and the resulting torque/speed curve for the double-cage motor in Fig. 11. The camera has its own fork-controlled time-base, which produces the vernier images in the corner of each picture and was used as a check on the uniformity of the taking rate.

The only practical limit set on the rate at which the camera may take is that due to the labour involved in analysing the film record. At rates of taking above 400 pictures per second (in the case of the 1 000 r.p.m. motors under test) this labour becomes excessive and only justified in exceptional cases, such as the provision of a standard of reference or the consideration of a small part of the torque/speed curve.

The high-speed camera method has the advantage that it gives results which are fundamental, the theoretical accuracy of which is almost unlimited.

It will be seen from Figs. 8, 9 and 11 that some extension of the range of measurements into the hypersynchronous region has been made. This is done by driving the motor under test above its synchronous speed, allowing it to run freely by inertia, and then applying the stator voltage.

(7) COMPARATIVE COSTS OF THE VARIOUS METHODS

Before otherwise comparing the methods described, it will be well to form a clear idea of their relative cost.

(i) The apparatus required for the brake-loading method of test is of small cost, and is available in almost every laboratory and test shop.

(ii) The rotational accelerometer is beyond the financial means of most organizations, and is not portable.

(iii) A simple motion-picture camera of the type used in these tests, or a slightly better model, would be within the means of most manufacturers and of many laboratories where the amount of work which is done on induction motors justifies frequent studies of their torque characteristics.

(iv) The high-speed camera is comparable in first cost with the rotational accelerometer, but is portable, and can therefore be made available on hire wherever the work justifies this.

(8) COMPARISON OF METHODS OF MEASURING TORQUE

(i) The brake-loading method is of very low cost, and gives results of high accuracy at the working speeds of the motor, obtained from short calculations. The range of speeds over which observations may be made is very limited, however, and the method gives no data concerning regions of poor torque performance or the possibility of crawling.

(ii) The rotational accelerometer is of high cost and is not portable. It gives results of moderate and uniform accuracy at all speeds, which require a considerable amount of correction for constants of the measuring apparatus. Results are obtainable at any speed, but are obscured completely near zero speed if the motor under test is started from rest (which, however, should never be necessary). Effects of parasitic synchronous torques and similar defects of torque performance are made immediately evident in the oscillograms, but are difficult to estimate quantitatively by this method.

(iii) The method using a simple form of motion-picture camera is of low cost, but gives results of low accuracy as the working speeds of the motor under test are approached. The accuracy increases at low speeds. After careful analysis occupying some time, results are obtainable at any speed, but the accuracy is impaired if the motor is started from rest. The method reveals

regions of poor average torque performance, but does not show parasitic synchronous torques.

(iv) The high-speed camera is of high first cost but is portable. It is capable of measuring torque from acceleration with moderate accuracy at all speeds, higher accuracy being obtained at the cost of increased labour in analysis. Results are obtainable by this method under all conditions of speed and acceleration, and it is possible, by magnifying the time axis and therefore the speed axis of relevant parts of the torque/speed curve, to obtain quantitative data on all defects in torque performance.

(9) CONCLUSIONS

A description and comparison of four methods of measuring torque in induction motors have been given, and it is shown that it is possible to develop methods based on the analysis of motion-picture records. The use of a simple form of motion-picture camera has great advantages from the point of view of cost, but its failure to reveal parasitic synchronous torques is a severe limitation. The use of a high-speed camera provides a method of measurement which is fundamental and capable of considerable accuracy, but is laborious and therefore only suitable for research or for providing a standard of reference.

(10) ACKNOWLEDGMENTS

The experiments described in the paper, with the exception of those employing the rotational accelerometer, were performed at King's College, London, under the direction of Prof. J. K. Catterson-Smith. The rotational-accelerometer tests were carried out at Manchester by the courtesy of the Metropolitan-Vickers Electrical Company, Ltd. The use of the high-speed camera was made possible by the courtesy of the Western Electric Company. The author's thanks are due to the authorities and firms mentioned.

DISCUSSION ON "A SLIDING-RATE METER"*

Mr. D. J. Bolton (*communicated*): The author says that the tariff problem "reduces to a question of a suitable measuring instrument." This is surely putting the cart before the horse. One must have something specific to measure before setting out to measure it, and the question is—What quantity does the sliding-rate meter measure? Putting the question another way, I would ask the author to formulate any tariff whatsoever (no matter how complicated) for which his meter would record the monthly bill.

The supply engineer has two very practical tasks to perform, namely to state his price for electric supply precisely and unmistakably, and then to measure the supply on the lines of this tariff. The author cannot help in the second of these tasks unless he can relate it to the first. The statement that "the meter indicates a figure which is proportional to the payment due" merely begs the question of what *is* the payment due. It would almost appear that the tariff would have to be stated not in terms of a defined physical quantity but in terms of a reading on a particular sort of meter.

Mr. E. V. Clark (Australia)(*communicated*): Without in any way criticizing the mechanism of the meter described by the author, one may suggest that if it is intended to be the sole metering instrument of a supply it has been designed the wrong way round, in that a tariff aiming to encourage a high load factor should charge a low rate per unit at heavy loads, and a higher rate at low loads; whereas Dr. Unz's meter does just the reverse.

A few examples will readily demonstrate this.

Case A. Peak load, 10 kW. Annual consumption, 14 400 units. Load factor, 16·6 %. Average load while running, 5 kW; but with occasional peaks up to 10 kW, of several hours' duration. Supply metered by an Unz meter, 10 kW rating, so calibrated as to charge at the rate of 0·5d. per unit at negligible load, and 1·5d. at full load, a straight-line characteristic being assumed, for simplicity.

With average weighted load, while running, of 5 kW, this consumer is charged at an average rate of 1d. per unit; and his annual bill is £60.

Case B. Peak load, 10 kW. Annual consumption, 87 600 units, 100 % load factor. The meter runs at full speed throughout, and therefore charges all units at 1·5d., the annual bill being £540. Thus the Unz meter charges the 100 % load-factor consumer at a 50 % higher unit rate than the consumer who has a poor load factor.

With the sliding scale reversed, so that the meter charges 1·5d. at negligible load, and 0·6d. at full load, the consumer in Case A still pays at 1d. per unit; but the 100 % load-factor consumer pays only 0·5d. per unit.

Case C. Identical with Case A, except that the peaks exceeding 5 kW, which sometimes reach 10 kW, never last more than a few minutes. The meter appropriate to this consumer will be rated at 5 kW, its overload capacity being ample to deal with peaks of short duration; and, being of the Unz type, the meter will charge at 0·5d. per unit at negligible load, rising to 1·5d. at 5 kW load. This consumer will therefore be charged at about 1·5d. for his supply, or 50 % more than Consumer A, though he is palpably more satisfactory to the supply authority.

Case D. Identical with Case A, except that the consumer has installed a 20-b.h.p. motor and the supply authority has in consequence put in a 20-kW meter, i.e. one that only reaches a charge of 1·5d. per unit when the load reaches 20 kW. This consumer, with an

* Paper by Dr. M. Unz (see page 85).

average weighted load of 5 kW, now gets his supply at an average charge of 0·75d. per unit. In other words, he effects a saving of 25 % on his annual bill by putting in a motor which is twice as large as necessary; at the same time he is operating at a shockingly poor power factor, which certainly should justify a surcharge.

These examples will suffice to show that the author's meter, used alone, is quite unsuitable for a general power tariff. It is equally unsuited to domestic supply; for a consumer with a 10-amp. meter and sundry radiators which he hardly ever used would have an absurdly low annual bill, quite unremunerative to the supply authority; and yet all units used by a power appliance taking 0·5 kW or more would be charged for at appreciably above the minimum rate.

There are, however, cases where the author's type of sliding scale operates in the right direction, as in the following example.

Case E. Annual consumption and peak load identical with Case A; but the average load, while running, is 10 kW. In other words, this consumer uses 10 kW for 16·6 % of the year, whereas Consumer A averages 5 kW for 32·2 % of the year. The charge to Consumer E is evidently at the rate of 1·5d. per unit, and his annual bill is 50 % greater than that of Consumer A. This difference is evidently in the right direction; for, palpably, the diversity factor *inter se* of consumers of the type of Case A is likely to be much better than that of consumers of the type of Case E.

This suggests that the positive sliding scale of the author's meter, though differentiating wrongly between consumers of varying load factors, may be appropriate to differentiate between different consumers of the same load factor in accordance with their probable effect upon the general diversity factor. A two-part tariff may differentiate appropriately with regard to load factor, but ignores diversity factor. It therefore seems that the most promising field for the use of the authors' meter would be to measure the unit charge in a two-part tariff where the standing charge was metered or computed in any of the ordinary ways.

A two-part tariff of this kind, however, is likely to remain purely of academic interest, for the Unz attachment would no doubt materially increase the cost of meters; and the lot of the meter superintendent who had the responsibility of supplying a differently calibrated meter to every house of different rateable value would not be an enviable one. The use of such a meter for all domestic consumers who are charged on the two-part tariff therefore seems to be utterly impracticable. Though the author's meter would appear to meet the requirements of the Electricity Acts if universally applied, it would probably fall foul of the Wimbledon decision if applied merely in those limited cases where the supply engineers became aware that electricity was being used extremely lavishly.

Dr. M. Unz (*in reply*): In reply to Mr. Bolton, the sliding-rate meter measures the power supplied, exactly like a standard watt-hour meter. The speed of its rotor, however, is not proportional to the power. It is proportional to the price of the power for a unit of time, at a rate which varies with the load. As a result the meter does not integrate the supplied energy in watt-hours, but the amounts charged for this energy at the different loads.

In other words the readings of the meter, though derived from an electrical measurement, are in terms of money. The device actually combines the performance of both the consumption and demand meters with the action of a calculating machine; it indicates a figure proportional to the total amount of the bill directly on the dial.

The details of the tariffs suitable for use with the sliding-rate meter were beyond the scope of the paper. The numerical examples calculated by Mr. Clark are, I think, misleading because the tariff assumed does not incorporate either a minimum-payment guarantee or a block-rate for the base price, as suggested on page 85 of the paper.

The price law described in Cases (A) and (B) in the above examples can be shown in Fig. 10 of the paper as a straight line through the points of co-ordinates (0 kW; 1 key unit/kWh) and (5 kW; 2 key units/kWh).

Assuming now a block rate for the values of the key units:

Up to 50 000 key units per year, 0·5d. per key unit;

From 50 001 to 200 000 key units per year, 0·25d. per key unit;

From 200 001 to 400 000 key units per year, 0·15d. per key unit;

we arrive at the following results:—

Case (*A*). With 14 400 units per year consumed at an average weighted load, while running, of 5 kW, the sliding-rate meter would indicate 28 800 key units per year. This number of key units, valued at 0·5d., amounts to £60. The average price per kWh is 1d. (against 0·5d. for the same power supplied continuously).

Case (*B*). With 87 600 units per year consumed at a continuous load of 10 kW, the sliding-rate meter would indicate 262 800 key units per year. This number of key units at 0·15d. from the block rate amounts to £164 5s., and the average unit price is this time only 0·45d.

Similar results can obviously be obtained for all the other cases. The sliding-rate meter automatically overcharges the loads with a bad load factor.

As to the tendency of certain consumers to increase the size of their equipment in order to get a larger meter which would work at the low end of its characteristic, such action would be checked by the necessary initial expenditure. Many supply companies might even consider this trend as an advantage for developing the use of electricity.

THE BENEVOLENT FUND

42ND ANNUAL GENERAL MEETING, 9TH MAY, 1940

Mr. Johnstone Wright, President, took the chair at 5.50 p.m.

The notice convening the meeting was taken as read. The minutes of the 41st Annual General Meeting held on the 11th May, 1939, were also taken as read and were confirmed and signed.

The Report of the Committee of Management (see below), and the Statement of Accounts for the year 1939 (see page 604), were presented and, on the motion of the chairman, seconded by Mr. A. E. Quenzer, were unanimously adopted.

The chairman proposed, and it was unanimously resolved, that Mr. A. J. Attfield, F.C.A., be elected Honorary Auditor for the year 1940.

The chairman reported the constitution of the Committee of Management for the year 1939–40 (see page 102).

The meeting then terminated.

REPORT OF THE COMMITTEE OF MANAGEMENT OF THE BENEVOLENT FUND FOR 1939

Capital

The Capital Account stood on the 31st December, 1939, at £23 863 2s. 2d., which is invested.

Receipts

The Income for 1939 from dividends, interest and annual subscriptions, was as follows:—

	£	s.	d.
Dividends and Interest	1 110	17	4
3 305 Annual Subscriptions	1 651	16	3
	£2 762	13	7

Donations

In addition to the foregoing, the Fund benefited during the year by the following subscriptions and donations:—

	£	s.	d.
I.E.E., part surplus from Summer Meeting	150	0	0
North-Western Centre:			
Golf Tournament	125	0	0
Manchester Engineers' Ball	15	15	0
Mersey and North Wales (Liverpool) Centre:			
Golf Tournament	88	0	0
Lecture	22	11	9
Electrical Engineers' Ball	19	8	3
North Midland Centre:			
Golf Tournament	66	2	9
Collections at Meetings	11	5	6
Western Centre: Collections at Meetings	40	10	9
South Midland Centre: Electrical Engineers' Ball	30	0	0
Incorporated Municipal Electrical Association	10	10	0
Incorporated Municipal Electrical Association: Golf Tournament	18	19	6
"The Twenty Five Club"	26	5	0
Argentine Centre	19	14	0
National Register of Electrical Installation Contractors	10	10	0
Scottish Centre: Golf Tournament	6	12	0
Institution of Post Office Electrical Engineers	5	5	0
Henley's Telegraph Works Co., Ltd.	25	0	0
Messrs. Merz and McLellan	15	15	0
General Electric Co., Ltd.	10	10	0
Messrs. Mavor and Coulson, Ltd.	5	5	0
H. Marryat	169	4	7
Lord Hirst of Witton	30	0	0
Anonymous	20	0	0
E. Fawssett	14	9	10
Anonymous	12	0	0
A. Atherton	10	10	0
G. W. Smart	10	10	0
B. E. Stott	10	10	0
"F. C. E. B."	10	0	0
W. Meacher	10	0	0
B. Price	10	0	0
H. W. Kolle	8	13	10
J. S. Pickles	7	6	6
S. B. Donkin	7	4	10
S. Evershed	7	4	10
A. P. M. Fleming	7	4	10
F. Gill	7	4	10
P. Rosling	7	4	10
H. T. Young	7	4	10
J. A. B. Hellaby	7	0	0
G. H. Nisbett	6	18	0
J. Anderson	5	18	0
W. B. Cleeves	5	5	0
V. E. Faning	5	5	0
S. H. Pook	5	5	0
G. Roddam	5	5	0
L. C. F. Bellamy	5	0	0
J. M. Donaldson	5	0	0
J. M. Kennedy	5	0	0
R. G. Kilburne	5	0	0
K. A. Scott-Moncrieff	5	0	0
E. A. Short	5	0	0
E. Wythe Smith	5	0	0
N. S. Tennant	5	0	0
and 3 240 donations of under £5	1 117	0	9
	£2 287	10	0

Electrical Engineers' Ball

The annual Electrical Engineers' Ball, held on the 10th February, 1939, realized a surplus of £240 19s. 2d., which was handed to the Fund.

Owing to the war, the Ball was not held in February, 1940, and the Fund will thereby suffer a loss of revenue of between £200 and £250. The Committee expect that the demands on the Fund in this and coming years will be heavy owing to distress caused by the War, and they therefore appeal to those who normally attend the Ball to send a special donation to compensate in some way for this loss of revenue.

Income

The total income from all sources for 1939 was £5 291 2s. 9d., which compares with £5 448 7s. 5d. for 1938.

Grants

Applications for assistance were made by or on behalf of 83 persons during 1939, and the Committee after careful consideration made grants in 80 of the cases. In assisting these persons the Fund also provided for the necessities of 58 dependants.

The total amount of the grants was £3 814 15s. 7d. which compares with £3 826 5s. 6d. in 1938.

Donors and Subscribers

Lists of the names of donors and subscribers are issued to members of The Institution annually, and the Committee of Management desire to tender their cordial thanks to all the contributors. The Committee earnestly hope that all members of The Institution will continue to give the Fund their active support.

Local Honorary Treasurers

The Committee wish to express cordial appreciation to Local Honorary Treasurers for their untiring efforts in stimulating an interest in the Fund among the members in the Local Centres and their valuable help in the investigation of applications for assistance.

Refund of Income Tax

The Fund is able, under the provisions of the Finance Act, 1922, to recover income tax on annual subscriptions, provided the subscribing member signs a deed of covenant to give a fixed amount per annum for a minimum period of 7 years. A number of contributors of large amounts have already agreed to subscribe under this arrangement, and if any other member wishes to subscribe under the scheme the Honorary Secretary of the Fund will be pleased to supply him with the necessary form and particulars.

Wilde Fund

The Capital Account stood, on the 31st December, 1939, at £3 049 16s. 2d., all of which is invested and brings in an annual income of about £104.

The balance standing to the credit of the Income Account (from which, under the Trust Deed, only full Members and their dependants can benefit) on the same date was £92 3s. 6d.

Grants amounting to £104 were made from this Fund during the year.

The income of this fund is administered by the Committee of Management of the Benevolent Fund, and its Accounts are published in the *Journal*.*

* See page 604.

THE BENEVOLENT FUND OF THE INSTITUTION OF ELECTRICAL ENGINEERS.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR 1939.

Dr. EXPENDITURE

Year ended 31 Dec., 1938. £ s. d.		£ s. d.
3,826 5 6	To Grants	3,814 15 7
61 18 1	,, Printing, Stationery, Postage, etc.	35 15 3
1,560 3 10	,, Unexpended Balance carried to Balance Sheet ..	1,440 11 11
£5,448 7 5		£5,291 2 9

INCOME. **Cr.**

Year ended 31 Dec., 1938. £ s. d.		£ s. d.	£ s. d.
1,080 8 10	By Dividends and Interest		1,110 17 4
201 11 6	,, London Electrical Engineers' Ball		240 19 2
	,, Donations of £5 and over:—		
	Mersey and North Wales (Liverpool) Centre Golf Tournament	88 0 0	
	North-Western Centre Golf Tournament	125 0 0	
	North Midland Centre Golf Tournament	66 2 9	
	Incorporated Municipal Electrical Association, Golf Tournament	18 19 6	
	Scottish Centre Golf Tournament	6 12 0	
	Mersey Centre Electrical Engineers' Ball	19 8 3	
	North-Western Centre, Manchester Engineers' Ball ..	15 15 0	
	South Midland Electrical Engineers' Ball	30 0 0	
	Other donations	800 11 9	
1,571 15 2			1,170 9 3
1,310 11 11	,, Donations under £5	.. ..	1,117 0 9
1,184 0 0	,, Annual Subscriptions	.. ..	1,651 16 3
(Legacy) 100 0 0			
£5,448 7 5			£5,291 2 9

BALANCE SHEET, 31st DECEMBER, 1939.

Dr. LIABILITIES.

		£ s. d.
To Capital Account:—		
As per last Balance Sheet		23,863 2 2
,, Income and Expenditure Account:—		
As per last Balance Sheet	£4,941 11 5	
Unexpended Balance in 1939	1,440 11 11	
	6,382 3 4	
,, Profit on redemption of £500 Canada $3\frac{1}{2}$ % Stock (1930–50)	21 4 0	
		6,403 7 4
,, Grants authorized but not yet disbursed		52 0 0
,, Sundry Creditors		6 12 10
,, Subscriptions and Donations received in advance		14 5 0
		£30,339 7 4

ASSETS. **Cr.**

		£ s. d.
By Investments (Capital), at cost:—		
£961 7s. 7d. Cape of Good Hope 3 % Stock (1933–43)		950 0 0
£420 London and North Eastern Railway 4 % First Preference Stock		503 18 3
£450 London, Midland and Scottish Railway 4 % Debenture Stock		551 0 9
£750 East Indian Railway $3\frac{1}{2}$ % Debenture Stock		737 18 0
£300 London, Midland and Scottish Railway 4 % Guaranteed Stock		333 11 6
£500 New Zealand $3\frac{1}{2}$ % Stock (1940)		486 18 6
£5,800 $3\frac{1}{2}$ % War Stock		5,783 6 1
£350 New South Wales 4 % Stock (1942–62)		336 18 6
£2,580 4 % Funding Stock (1960–90)		2,123 15 6
£3,295 $3\frac{1}{2}$ % Conversion Stock (1961)		2,512 11 10
£450 Commonwealth of Australia 5 % Stock (1945–75)		438 16 0
£450 Tynemouth Corporation 5 % Stock (1947–57)		457 7 3
£950 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)		988 5 6
£1,000 Southern Railway 5 % Redeemable Guaranteed Preference Stock (1957)		1,028 7 0
£1,000 Southern Railway 5 % Guaranteed Preference Stock		1,000 3 0
£1,000 Hastings Corporation 5 % Stock (1947–67)		980 2 0
£800 London Passenger Transport Board 5 % "A" Stock (1985–2023)		808 2 6
£700 Ayr County Council 5 % Stock (1947–57)		733 7 0
£1,000 Commonwealth of Australia 4 % Stock (1955–70)		1,012 13 0
£900 South Essex Waterworks Co. Perpetual Debenture 4 % Stock		1,014 4 6
£650 London County Council $2\frac{3}{4}$ % Consolidated Stock (1960–70)		602 19 6
£332 2s. 5d. Newcastle and Gateshead Water Co. 5 % Consolidated Preference Stock		478 16 0
(*Market value 31st December*, 1939, *£24,013 14s. 3d.*)		£23,863 2 2
,, Investments (Income) at cost:—		
£717 17s. 7d. Newcastle and Gateshead Water Co. 5 % Consolidated Preference Stock	£1,034 18 6	
£1,050 London County Council $2\frac{3}{4}$% Consolidated Stock (1960–70)	977 15 9	
£1,000 3 % Funding Stock (1959–69)	1,033 5 6	
£1,000 $4\frac{1}{2}$ % Conversion Stock (1940–44)	1,053 18 0	
		4,099 17 9
(*Market value 31st December*, 1939, *£3,617 9s. 1d.*)		
,, Sundry Debtors		95 5 7
,, Cash:—		
At Bank	£2,279 4 0	
In hands of Honorary Secretary	1 17 10	2,281 1 10
		£30,339 7 4

I have audited the above Balance Sheet and Income and Expenditure Account with the Books and Vouchers and certify them to be correct, and have verified the Investments with Certificates from Banks.

ARTHUR J. ATTFIELD, F.C.A.
Honorary Auditor.

20th April, 1940.

PROCEEDINGS OF THE INSTITUTION

957TH ORDINARY MEETING, 11TH APRIL, 1940

Mr. Johnstone Wright, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 28th March, 1940, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The following list of donors to the Library was taken as read, and the thanks of the meeting were accorded to them: Air Ministry; W. Aitken; R. W. Allen, C.B.E.; American Institute of Electrical Engineers; American Radio Relay League, Inc.; American Society of Mechanical Engineers; ASEA Electric Co., Ltd.; Association of Engineers in Burma; Association of Municipal Electrical Undertakings in South Africa; The Astronomer Royal; Babcock and Wilcox, Ltd.; J. W. Beck; R. Belfield; Belling and Lee, Ltd.; Benn Bros., Ltd.; Blackie and Son, Ltd.; Major C. H. Brazel, M.C.; British Broadcasting Corporation; British East African Meteorological Service; British Electrical and Allied Industries Research Association; British Electrical Development Association; British Engine Boiler and Electrical Insurance Co., Ltd.; British Engineers Export Journal; British Standards Institution; Bureau of Standards, U.S.A.; Cable and Wireless, Ltd.; Cambridge University Press; Canadian Engineering Standards Association; Central Electricity Board; Centro Volpi di Elettrologia; Cheap Steam, Ltd.; Conférence Internationale des Grands Réseaux Electriques à Haute Tension; L. J. Comrie, M.A., Ph.D.; Copper Development Association; Department of Scientific and Industrial Research; Department van Verkeer en Waterstaate; P. Dévédec; P. W. Dharap; H. M. Dowsett; Electricity Board for Northern Ireland; Electricity Commissioners; Electricity Supply Authority Engineers' Association of New Zealand; Electricity Supply Commission, South Africa; Electrodepositors' Technical Society; C. F. Elwell; Federation of British Industries; J. L. Ferns, B.Sc.; C. Frobisher; General Electric Co., Ltd.; General Post Office (Public Relations Department); John Gifford, Ltd.; G. Giorgi; Glenfield and Kennedy, Ltd.; B. Hague, D.Sc., Ph.D.; Hamish Hamilton, Ltd.; Miss C. Haslett, C.B.E.; F. W. Hewitt, M.Sc.; A. W. Hirst, M.Sc.(Eng.); Hodder and Stoughton, Ltd.; Home Office; Hull Association of Engineers; P. Hunter-Brown; A. M. Hyamson; Hydro-Electric Development, New Zealand; Hydro-Electric Power Commission of Ontario; W. S. Ibbetson, B.Sc.; Iliffe and Sons Ltd.; Imperial Institute; Incorporated Municipal Electrical Association; Incorporated Radio Society of Great Britain; Indian Posts and Telegraphs Department; Institute of Engineers (India); Institute of Welding; Institution of Railway Signal Engineers; Institution of the Rubber Industry; International Electrotechnical Commission; Dr. A. E. Kennelly; T. Kiu; W. King, Ltd.; Leeds Association of Engineers; London and Home Counties Joint Electricity Authority; Longmans, Green and Co.; Dr. I. Lucchi; McGraw-Hill Publishing Co., Ltd.; Manchester Association of Engineers; Prof. E. W. Marchant, D.Sc.; Meteorological Office; Methuen and Co., Ltd.; Mines Department; Ministère des Travaux Publics; Mond Nickel Co., Ltd.; National Electrical Manufacturers Association; National Physical Laboratory; George Newnes, Ltd.; New South Wales Department of Works; New Zealand Hydro-Electric Development; New Zealand Post and Telegraph Department; C. A. Parsons and Co., Ltd.; R. S. Phillips; Sir Isaac Pitman and Sons, Ltd.; Plastics Press, Ltd.; Portuguese Ministry of Public Works and Communications; Sir Arthur H. Preece; Public Works, Roads and Transport Congress and Exhibition Council; Sir Robert Rankin; E. T. A. Rapson, M.Sc.(Eng.); R.C.A. Institutes Technical Press; H. Rissik; Royal Alfred Observatory, Mauritius; Royal Swedish Institute for Engineering Research; A. Rubin; Dr. A. Russell, F.R.S.; D. Rutenberg; Science Museum; Société Financière de Transports et d'Entreprises Industrielles; E. and F. N. Spon, Ltd.; Standard Telephones and Cables, Ltd.; Sudan Engineering Society; Surveyor General of India; F. H. Taylor; Taylor and Francis, Ltd.; The Technical Press, Ltd.; Dr. H. A. Thomas; Thornton, Butterworth, Ltd.; United States Department of Commerce; H. Waddicor, B.Sc.; R. P. Wallis, Ph.D.; A. G. Warren, M.Sc.; H. E. Wimperis, C.B., C.B.E., M.A.; G. Windred; and World Power Conference (British National Committee).

A paper by Mr. J. W. Gibson, M.Eng., Associate Member, entitled "The High-Rupturing-Capacity Cartridge Fuse, with special reference to Short-Circuit Performance," was read and discussed. The paper was illustrated by a cinematograph film.

A vote of thanks to the author, moved by the President, was carried with acclamation.

958TH ORDINARY MEETING, 25TH APRIL, 1940

Mr. Johnstone Wright, President, took the chair at 6 p.m.

The minutes of the meeting held on the 11th April, 1940, were taken as read and were confirmed and signed.

The President referred to the death of Mr. P. F. Rowell, Secretary from 1909 to 1939, and paid tribute to his loyal and devoted services to The Institution. Those present then stood in silence as a mark of esteem.

Messrs. W. R. Hackworth and R. J. H. Curran were appointed scrutineers of the ballot for the election and

transfer of members and, at the end of the meeting, the President reported that the members whose names appeared on the lists (see page 514) had been duly elected and transferred.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

Messrs. P. K. Davis, F. Pooley and A. E. Quenzer were appointed scrutineers of the ballot for the election of new Members of Council.

The President: Once a year the Council invite a distinguished scientist to talk to us on the subject which he has made his own, and to deliver the Kelvin Lecture. This evening we are to hear Dr. C. G. Darwin. Before calling on him, however, I have another pleasant duty to perform, namely the presentation of the Faraday Medal which has been awarded by the Council to Dr. Alexander Russell, Past-President and Honorary Member of The Institution. He has been awarded the Medal under two headings: scientific achievement, and conspicuous services rendered to the advancement of electrical science. Under the first heading he has many achievements to his credit. For a long time his work on alternating-current phenomena, inductance, and electrostatics, has been recognized and his knowledge regarded as authoritative. His investigation of the distribution of electricity on adjacent spheres is probably the most complete research on the theory of the sphere gap, which is now universally used as a standard of high potential difference in electrical testing. Perhaps, however, his greatest achievement comes under the second heading—conspicuous services rendered to the advancement of electrical science. Dr. Russell's work as a teacher is so well known that there is no need for me to elaborate it. He and Faraday House are synonymous. That establishment has produced several Presidents of our Institution. Old Faradians are to be found in almost every part of the world, and all of them owe much to the inspiration of Dr. Russell's teaching and fatherly guidance. In addition to this, Dr. Russell has found time to be President of the Physical Society and of the Junior Institution of Engineers, and his contributions to scientific literature are too numerous to mention. Quite apart from his scientific attainments, Dr. Russell has, by his outlook on life, done much to promote brotherhood amongst all those with whom he has come in contact, and I am sure that I voice the feelings of every member of The Institution in wishing him good health and happiness in his retirement.

The President then, amid applause, handed the Faraday Medal to Dr. Alexander Russell, M.A., D.Sc., LL.D., F.R.S.

Dr. Alexander Russell: I assure you that I fully appreciate the great honour you have done me in presenting me with this Medal, and I am very grateful for it. I thank you all from the bottom of my heart.

Dr. C. G. Darwin, M.C., M.A., F.R.S., then delivered the 31st Kelvin Lecture, entitled "Thermodynamics and the Lowest Temperatures."

Prof. W. M. Thornton: There are two occasions in the calendar of The Institution that are marked with red; one is the President's Address, in which he gives us the latest view of his own subject, and the other is the Kelvin Lecture, which is a kind of refresher lecture on a subject about which we may have forgotten. The special point about these refresher lectures is that they bring us back to first principles.

In thermodynamics there are two regions where first principles are of the highest importance. That at the high end, which is most important in connection with steam-turbine machinery, and that at the low end. So far as the latter is concerned, we have not got to the practical side of it in this lecture, but we have heard a most fascinating account of where matter begins to lose its properties and to become something with which we are not at all familiar. When I was a student, in 1895, I nearly went to Olszewski, and instead of becoming an electrical engineer I should then have been a low-temperature engineer; but fate decided otherwise. I join up with the subject of the lecture, however, in another way. Dr. Darwin has alluded to the magnetic properties of liquids at low temperatures, and some time ago it occurred to me that since liquid oxygen is a very magnetic substance, liquid ozone from its structure might be even more so. I accordingly wrote to Sir James Dewar and suggested this to him; he was interested and spent some time trying to make liquid ozone to examine its magnetic properties. I happened to meet Heath, his assistant, at a Royal Society Exhibition, and I said to him "How are you getting on with liquid ozone?" "Oh," he said, "some fool suggested to Sir James that it might have magnetic properties. We have made the stuff, but the trouble is that it is so unstable that if we drop it on the floor of the laboratory it blows the windows out!"

Dr. Darwin is, as you know, the famous son of a famous father whose work on the tides that shake the earth was well known to us about a generation ago, and the famous grandson of the man whose work shook not only the earth but the heavens as well. Now, as the head of the National Physical Laboratory, he is in charge of electrical standards and keeps us truly in our courses as electrical engineers. I beg to move that a hearty vote of thanks be accorded to him for the very interesting Kelvin Lecture he has delivered.

Mr. J. R. Beard: The latter part of the last century may be described as the golden youth of science. It was a time when it seemed as if the scientists were going to explain the whole of existence in comparatively simple ways and lead mankind into a better way of life. Since then we have grown up and realize that things are not so simple, and that science does not always work for good; indeed, at the present day we see science devoted to very sad ends. In the galaxy of scientists of that period there were two stars of the first magnitude: one was Charles Darwin and the other Lord Kelvin. Lord Kelvin left no family, but Charles Darwin left a most distinguished series of descendants, both children and grandchildren, who provide an interesting study in his own branch of science. It seems to me that apart from his own preeminence in physics Dr. Darwin, as one of these grandchildren, was an excellent choice for a lecturer to commemorate the memory of Kelvin, and he has mentioned another reason, in that Lord Kelvin was his godfather. The size of the audience which we have this evening, and which we always have for the Kelvin Lecture, shows that there is in all of us a desire occasionally to go outside our normal work and hear some-

thing about the higher flights; but it must be unfortunate for the lecturer who is called on to address such an audience, for he must feel that he runs a grave risk of talking above its head. Dr. Darwin seems to me, however, to have fulfilled most ably the qualifications for delivering a lecture of this kind and has combined clarity in presenting an abstruse scientific conception with a delightful dash of humour and even a hint of poetry. I have the greatest pleasure in seconding the vote of thanks to him.

The vote of thanks was then carried with acclamation.

68TH ANNUAL GENERAL MEETING, 9TH MAY, 1940

Mr. Johnstone Wright, President, took the chair at 6 p.m.

The notice convening the meeting was taken as read.

The minutes of the Ordinary Meeting held on the 25th April, 1940, were also taken as read and were confirmed and signed.

Messrs. A. H. Selwyn and E. J. Hampton were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the President reported that the members whose names appeared on the list (see page 614), had been duly elected and transferred.

The Premiums (see page 610) awarded by the Council for papers during the session were announced by the President.

The **President** next summarized the Annual Report of the Council for the year 1939–1940 (see page 575) and moved its adoption.

The motion after being seconded by **Mr. F. Gill** was put to the meeting and was carried unanimously.

Mr. W. McClelland (*Hon. Treasurer*) in submitting the Annual Accounts for 1939, said: " Twelve months ago, when presenting the Accounts for 1938, I referred in connection with expenditure in that year to the upward trend in prices of paper and printing, to the higher costs of the *Journal* and to the unsettled general economic conditions which then prevailed; and I gave as an example the increased cost of the *Journal*, which in 1936 amounted to £6 500 and had increased in 1938 to approximately £9 000. I mentioned also that the members of the Finance Committee and of the Council were watching very closely the continued increase in expenditure, and that committees were actively engaged in endeavouring to keep normal expenditure within the income from subscriptions and minor sources, i.e. excluding that portion of our income from interest and dividends.

" War conditions in 1939 rendered necessary certain special emergency expenditure, in addition to which the cost of publishing 'The History of The Institution' came in that year's Accounts. This has resulted in our income from subscriptions and minor sources being insufficient to meet all expenditure, and has necessitated an encroachment to the extent of £3 011 on the income derived from interest and dividends on capital subscribed by members in the past; but it should be noted that had it not been for such war and other special expenditure, much of which is non-recurring, we should have had a balance of about £700 of income from subscriptions and minor sources over our total expenditure.

" On referring to the Revenue Account, it will be seen that the total expenditure for the year amounts to £53 873, as against £49 692 in the previous year, an increase of £4 181. This increase is mainly accounted for by the special items to which I have already referred, for example A.R.P. £2 380, Central War Register £265, and the cost of 'The History' £1 129.

" Turning to the credit side, the total income for the year amounts to £58 335, against a figure of £57 037 in 1938, an increase of £1 298, due principally to the larger membership.

" The result of the year's working shows that the balance carried to the Balance Sheet was £4 185, as against £7 068 in 1938. The total assets are shown as £238 215 and the liabilities as £14 864, leaving a surplus of assets over liabilities of £223 351, a net improvement for the year of £3 063, as against £5 943 in 1938. The assets include the value of the building, which stands at the cost price of £73 028, provision to the extent of £12 095 for depreciation having been made by means of the Sinking Fund. Cash at various Centres at home and overseas amounts to upwards of £11 000, while our investments in Trustee Securities appear at their book value of £140 468. The market value of these investments at the 31st December, 1939, was £149 516, some £9 000 above their cost. It may be of interest to mention that at a recent valuation, taken at the end of April, their market value had further appreciated by £7 500, so that at the present time our investments are worth £16 500 above the cost or book value shown in the Accounts. As most members may know, prices of Trustee Stocks were continually falling up to December last year, and many industrial bodies in consequence had to write off in some cases heavy losses. I am sure the members will wish to join with me in paying tribute to the Council for the close scrutiny and the care which must have been taken over many years in the past in the selection of stocks for purchase from time to time by The Institution.

" The Accounts have been audited by chartered accountants and have been certified as correct. With a net surplus of £3 063 for the year, and with investments and cash standing at well over £150 000, I think we have good reason to congratulate ourselves on the very strong financial position of The Institution.

" I retire from the Honorary Treasurership at the end of this session, and I should like to take this opportunity of thanking not only the Secretary, Mr. Brasher, and his staff for their valuable assistance at all times, but also the President, who was Chairman of the Finance Committee for 2 years during my period of office, and Members of Council who have worked, and are still working, to secure the utmost economy consistent with progress and with the usefulness and general service of The Institution."

The motion for the adoption of the Accounts was seconded by **Mr. J. R. Beard** and was carried unanimously.

A vote of thanks to Mr. W. McClelland, C.B., O.B.E.,

for the excellent work which he had done as Hon. Treasurer during the past 3 years was proposed by the **President** and was carried with acclamation.

The **President** also moved "That the best thanks of The Institution be accorded to (*a*) the Hon. Secretaries of the Local Centres; and (*b*) the Local Hon. Secretaries abroad, for their valuable services during the past year." This motion was put to the meeting and was carried with acclamation.

Mr. H. W. Grimmitt then moved "That Messrs. Allen, Attfield and Co. be appointed auditors for the year 1940–41." The resolution was seconded by **Mr. J. L. Wilson** and was carried unanimously.

The meeting then terminated.

INSTITUTION NOTES

CENTRAL REGISTER OF NATIONAL SERVICE

There has been a marked increase of late in the number of vacant and new appointments in Government Departments and firms engaged on work of national importance which have been notified to the Central Register, and for which the Electrical Engineering Sub-Committee have selected volunteers. Names of over 2 000 members have been put forward for the consideration of the Ordering Departments, and it is known that some 700 of these have taken up their duties.

At the time of going to press, the serious trend of events renders the necessity for the registration of all professional men all the more urgent, and a call is being issued to all members who have not already done so to return their registration cards. In this connection the following message has been received from the Minister:—

From Mr. Ernest Bevin, Minister of Labour and National Service

"Members of The Institution of Electrical Engineers are already familiar with the Central Register and its purpose. At my request the professional organizations of engineers collaborating with the Central Register have agreed to re-circularize all of their members not already on the Register. I ask those members who receive this request to respond at once.

"Many professional engineers are already engaged on work of national importance. I want them to stay where they are at present. At the same time I want a complete record of names and qualifications so that, if need arises, I may be able to call on their services for even more urgent or vital work."

THE DISTRIBUTION OF UNIVERSITY GRADUATES ON WORK OF NATIONAL IMPORTANCE

Reference was made in "Institution Notes" last month to representations by the Council to the Minister of Labour and National Service on the correlated subjects of the training of electrical engineers and their allocation to the various forms of National Service; and it was announced (page 508) that the military service of certain classes of students would be postponed in order to allow them to complete their studies. Information has since been received that amendments to the procedure governing the work of the University Joint Recruiting Boards have now been put into force which will ensure an even distribution of those who have completed their academic training in accordance with the varying requirements from time to time of industry and of the Services.

Fuller details can be obtained by those immediately concerned, on application to the Secretary.

CONVERSAZIONE FOR OVERSEAS MEMBERS AND MEMBERS SERVING IN H.M. FORCES

It was, with reluctance, decided at the end of May that on account of the gravity of the situation the arrangements for the Conversazione and Reunion to be held on the 27th June must be cancelled.

LOCAL HONORARY SECRETARIES ABROAD

The Council have appointed Mr. M. A. Pike (Post and Telegraph Department, Dunedin, N.Z.) as Local Honorary Secretary for New Zealand, in place of Mr. P. H. Mason, deceased; and Mr. S. W. Redclift (Electrical Adviser and Electrical Inspector to Government of Bengal, 1, Harish Mukherji Road, Elgin Road P.O., Calcutta) as Local Honorary Secretary for India, in place of Mr. K. G. Sillar, who has returned to this country.

They have also confirmed the appointment by the New South Wales Committee of Mr. C. A. Saxby as Honorary Secretary of that Committee.

COUNCIL'S NOMINATIONS FOR ELECTION TO THE COUNCIL

The following have been nominated by the Council for the vacancies which will occur in the offices of President, Vice-Presidents, Honorary Treasurer, and Ordinary Members of Council, on the 30th September, 1940:—

President. (*One Vacancy.*)
J. R. Beard, M.Sc.

Vice-Presidents. (*Two Vacancies.*)
P. Dunsheath, O.B.E., M.A., D.Sc.
Major V. Z. de Ferranti, M.C.

Honorary Treasurer. (*One Vacancy.*)
E. Leete.

Ordinary Members of Council.

MEMBERS. (*Four Vacancies.*)

H. C. Lamb. E. B. Moullin, M.A., Sc.D.
F. Lydall. J. S. Pringle, O.B.E.

ASSOCIATE MEMBERS. (*Two Vacancies.*)

H. W. Grimmitt. F. Jervis Smith.

COMPANION. (*One Vacancy.*)

The Rt. Hon. The Viscount Falmouth.

PREMIUMS

At the Annual General Meeting held on the 9th May the President announced that the Council had made the following awards of Premiums for papers during the session 1939–40:—

The Institution Premium (*value* £25).
G. F. SINCLAIR. "The Trolleybus."

The Ayrton Premium (*value* £10).
G. T. WINCH and A. M. MIDGLEY "Electronic Musical Instruments and the Development of the Pipeless Organ."

The Fahie Premium (*value* £10).
H. H. HARRISON, M.Eng. "Telegraphic Typesetting."

The John Hopkinson Premium (*value* £10).
W. D. HORSLEY "Operating Experience with High-Voltage Alternators."

The Kelvin Premium (*value* £10).
T. L. ECKERSLEY, B.Sc., Ph.D., F.R.S. "Analysis of the Effect of Scattering in Radio Transmission."

The Paris Exhibition (1881) *Premium* (*value* £10).
B. P. DUDDING, M.B.E., Ph.D., and W. J. JENNETT, B.Sc.(Eng.). "Statistics and Engineering Practice."

An Overseas Premium (*value* £5).
J. R. BROOKMAN, M.E. "The Maintenance of Relays and Associated Equipment."

An Overseas Premium (*value* £5).
G. BABAT and M. LOSINSKY "Heat Treatment of Steel by High-Frequency Currents."

A Premium (*value* £10).
H. L. THOMAS, B.Sc. (Eng.). "Insulation Stresses in Transformers, with special reference to Surges and Electrostatic Shielding."

A Premium (*value* £5).
H. E. COX and L. DRUCQUER "Oil-less Metalclad Switchgear for Medium-Voltage A.C. Circuits up to 660 Volts, Three-Phase."

A Premium (*value* £5).
J. W. GIBSON, M.Eng. "The High-Rupturing-Capacity Cartridge Fuse, with special reference to Short-circuit Performance."

A Premium (*value* £5).
Prof. A. O'RAHILLY, M.A., B.Sc., Ph.D., D.Litt. "A Note on Self-Induction."

A Premium (*value* £5).
Prof. J. J. RUDRA, M.A., B.Sc., Ph.D. "Modifications of the Leblanc Phase-Advancer."

A Premium (*value* £5).
H. A. SIEVEKING, M.Sc. "Electrically Manufactured Steels."

WIRELESS SECTION PREMIUMS

The Duddell Premium (*value* £20).
T. WALMSLEY, Ph.D., B.Sc. "Wire Broadcasting Investigations at Audio and Carrier Frequencies."

A Premium (*value* £10).
W. WEST, B.Sc., and D. McMILLAN, B.Sc. "The Design of a Loud-Speaker."

A Premium (*value* £10) *jointly for the following three papers:*
J. S. McPETRIE, D.Sc., Ph.D., and J. A. SAXTON, B.Sc. "An Experimental Investigation of the Propagation of Radiation having Wavelengths of 2 and 3 Metres."
J. S. McPETRIE, D.Sc., Ph.D., and Miss A. C. STICKLAND. "Reflection Curves and Propagation Characteristics of Radio Waves along the Earth's Surface."
R. L. SMITH-ROSE, D.Sc., Ph.D., and H. G. HOPKINS, Ph.D., B.Sc. "Radio Direction-Finding on Wavelengths between 2 and 3 Metres (100 to 150 Mc./Sec.)."

METER AND INSTRUMENT SECTION PREMIUMS

A Premium (*value* £5).
F. O. MORRELL, B.Sc., and the late G. R. OMAN, B.Sc. "A Method of Measuring and Recording the Frequency Error of Alternating-Current Power Supplies."

A Premium (*value* £5).
D. M. MYERS, D.Sc. (Eng.), and W. K. CLOTHIER, B.Sc., B.E. "An Oscillographic Technique for Measurements in a Network Analyser."

TRANSMISSION SECTION PREMIUMS

The Sebastian de Ferranti Premium (*value* £20).

E. FAWSSETT, H. W. GRIMMITT, G. F. SHOTTER and H. G. TAYLOR, M.Sc.(Eng.).	"Practical Aspects of Earthing."

A Premium (*value* £10).

K. L. MAY.	"High-Voltage Distribution in Rural Areas."

The awards for papers read before the Students' Sections will be published later.

INDEX TO JOURNAL

Any member who proposes to bind the current volume of the *Journal* and would like to have an extra copy of the Index for filing apart from the bound volume of the *Journal* can obtain an additional copy on application to the Secretary.

JOURNAL—WARTIME ECONOMY

The following letter was sent last month to each member of The Institution:—

30*th May*, 1940.

DEAR SIR,

Since the outbreak of the war the price of paper has doubled and drastic paper rationing has been imposed by the Paper Controller. This has made it necessary to give urgent consideration to proposals to minimize increased costs and to save paper.

The Council consider that this can best be brought about by a slight amendment of a scheme which was under consideration before the war for making the *Journal* more useful and convenient to members.

In recent years the material in the *Journal* has necessarily become very highly specialized in character and the distribution of the complete *Journal* to every member, irrespective of the particular branch of electrical engineering in which he may be engaged, did not seem the most satisfactory method of providing members with the technical information they required in the most suitable form.

This led to consideration of the sub-division of the *Journal*, an added advantage of which would be a substantial saving in the cost of its production, which is one of The Institution's largest items of expenditure.

As a result of careful consideration of these proposals in the light of present circumstances the Council have decided to modify the method of compiling and issuing the *Journal*, as from the volume commencing in January next. The basis of the re-arrangement is that every member will in future receive, instead of the present monthly issue of the *Journal*, a monthly copy of a General division of the *Journal* in which will appear, as a new feature, abstracts of all papers accepted for publication, together with all material of general interest. In addition to being fairly full, the abstracts will be designed to bring out the main principles for the benefit of those members who have no specialized knowledge of the subjects of the papers. Papers will appear in full together with the Discussions in two separate divisions of the *Journal* under the main headings of "Power Engineering" and "Communication Engineering." The former will be issued six times a year and the latter quarterly, and they will be supplied only to those members who make application for them.

The Proceedings of the Wireless Section, which have in the past been issued as a separate publication in addition to being published in the *Journal*, will now be included in the "Communication Engineering" division. It is felt that many members of the Wireless Section will be glad to have the wider range of papers which will be available to them in this division, but continuity will be maintained by retaining the original title as a sub-title.

In more detail this division of the *Journal* will be as follows:—

Part I "General."

Addresses and Lectures of a general character.
Abstracts of all papers in Parts II and III.
Progress Reviews.
Formal Proceedings of The Institution.
Notes.
Obituaries.
Council's Report.
Accounts, etc.

Part II "Power Engineering."

Power Generation, Transmission and Distribution.
Power Applications.
Meters and Instruments.
Design of Machinery and Testing.
Formal Proceedings of the Meter and Instrument Section.
Formal Proceedings of the Transmission Section.

Part III "Communication Engineering."

Wireless and Television.
Telegraphy and Telephony.
Formal Proceedings of the Wireless Section.

All members will receive Part I, "General," free, but in order to effect the necessary saving in both paper and cost of production it is essential to ask members to make a small payment in respect of Parts II and III. The amount payable per annum for each of these Parts will be 7s. 6d. to members of all classes with the exception of Students and Graduates up to the age of 28, for whom it will be 2s. 6d. Individual numbers of Parts II and III will be supplied to members on request at a price of 2s. 6d. each.

Members are asked to complete and return as soon as possible the enclosed application form indicating whether they desire to receive Part II and/or Part III as from January 1941, and arrangements will be made for the amounts payable to be notified when the annual membership subscriptions fall due.

In advising members of the above arrangements the Council desire to emphasize that free advance copies of papers read at meetings will still be available as hitherto on application being made to the Secretary. Members will, therefore, be able to obtain copies of individual papers to be published in a Part to which they do not subscribe. Requests from members for free copies of

individual papers after their reading will be met in so far as surplus copies are available.

The scheme for dividing up the *Journal*—and particularly the charge to be made for Parts II and III—is regarded by the Council as primarily a war measure and will be subject to reconsideration and modification from time to time in the light of the experience gained.

In conclusion, I am desired to say that the Council hope that these arrangements, which they consider to be essential under present circumstances, will, at the same time, meet more adequately the needs of the majority of the members and maintain the character and prestige of the *Journal* as a complete record of British Electrical Engineering progress.

Yours faithfully,
W. K. BRASHER,
Secretary.

TECHNICAL OFFICERS FOR ROYAL AIR FORCE

The Royal Air Force requires a number of technical officers for employment on engineering, armament, and signals duties. Commissions in the Royal Air Force Volunteer Reserve will be granted for the duration of hostilities to suitable applicants between the ages of 21 and 50 years possessing the requisite personal and technical qualifications. Applications are invited from persons with the following minimum qualifications:

Engineer.

(1) Holders of Engineering Degrees.

(2) Holders of Engineering Certificates, or members of Engineering Institutions who also have 2 years' practical experience.

(3) Practical engineers who have served an apprenticeship followed by a number of years' experience in erecting or overhauling internal combustion engines or aeroplane structures, and with knowledge of the properties of engineering materials.

Armament.

(1) Holders of Engineering Degrees or Engineering Certificates, or members of Engineering Institutions with at least 2 years' practical experience, particularly those with experience in armament manufacture.

(2) Practical engineers who have served an apprenticeship followed by a number of years' practical engineering experience and with knowledge of the proportion of engineering materials.

Signals.

(1) Holders of Engineering or Science Degrees.

(2) Holders of Technical College or approved Institute Diplomas, and 2 years' experience in telecommunications engineering (preferably on the radio side).

(3) A number of posts are also available for candidates possessing a sound theoretical knowledge of elementary electricity and magnetism, of the principles of wireless telegraphic and telephonic communications and of transmitter circuits, modern wireless receiving apparatus, and apparatus for the measurement of high-frequency potentials and currents. Some practical experience in addition is desirable, and specialized knowledge in one or more of the practical aspects of telecommunications would be an asset.

Further particulars can be obtained from the Secretary, I.E.E.

Candidates should apply, in writing, to the Air Ministry, S.7.e.5., Adastral House, Kingsway, London, W.C.2, giving full particulars of their qualifications, training and experience. Candidates who are engaged on the production of aircraft, engines or accessories, or on other important national work, should not submit applications without first consulting their employers as to the possibility of their being spared for Royal Air Force duty.

COMMISSIONS IN ARMY TECHNICAL UNITS

Members will be aware that enrolment in the Army Officers Emergency Reserve is open to those over 31 years of age, who in due course will be considered for direct Commissions when their services are required. At the present time certain Corps, particularly the Royal Engineers, are more desirous of recruiting those with suitable technical qualifications who are under the above age. These can only obtain Commissions after service in the ranks, and any who are suitable will be specially enlisted and will then be eligible for recommendation by their Commanding Officers for training at an Officers' Cadet Training Unit.

Members wishing to have further details should communicate with the Secretary of The Institution, mentioning any change in their qualifications or employment since the date of forwarding their Central Register cards.

Those whose names are put forward will be enlisted from time to time as vacancies occur. They will in this way have special consideration when they join their Units, and a greater chance of obtaining Commissions in the Corps they desire to join than would be the case if they were to wait until they were called up under the Military Service Acts.

BRITISH STANDARDS

The Secretary has been asked by the British Standards Institution to draw attention to the following new Specifications:—

Cables and Flexible Cords for the Electrical Equipment of Ships (B.S. 883).

For some time past there has been a need for a Standard Specification for cables for use on board ship, particularly since rubber and paper cables for land use are now dealt with in separate specifications. In the recently-issued Third Edition of the I.E.E. Regulations for the Electrical Equipment of Ships there is a reference to B.S. 883. At the time of the publication of the I.E.E. Regulations that Specification was not actually available, but it has now been published. The Specification consists of four Sections and two Appendices, covering:—

(1) General.
(2) Vulcanized rubber-insulated cables, flexible cables and flexible cords.
(3) Impregnated paper-insulated and varnished cambric-insulated cables.
(4) Tests.
Appendix A. Identification of cores.
Appendix B. Spark-testing of rubber-insulated cables.

Copies of the new Specification can be obtained from the B.S.I., price 3s. 6d. each (3s. 10d. post free).

Specification for Front Lamps for Tram-Cars (BS/ARP. 41).

With a view to assisting passenger road-transport operators to comply with the Lighting (Restrictions) Order, 1940, as regards the masking of front lamps, a Specification has been issued by the British Standards Institution.

The first part of the Specification defines the conditions governing the use of front lamps on tram-cars, and a description is then given of a design which fulfils the conditions.

Copies of this Specification can be obtained from the B.S.I., price 3d. each post free.

PROCEEDINGS OF THE METER AND INSTRUMENT SECTION

91st Meeting of the Meter and Instrument Section, 5th April, 1940

Mr. F. E. J. Ockenden, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 15th March, 1940, were taken as read and were confirmed and signed.

A paper by Mr. J. L. Candler, B.Sc.(Eng.), Associate Member, entitled "Developments in Surge Recording by means of the Klydonograph," was read and discussed.

A vote of thanks to the author, moved by the Chairman, was carried with acclamation.

92nd Meeting of the Meter and Instrument Section, 3rd May, 1940

Mr. F. E. J. Ockenden, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 5th April, 1940, were taken as read and were confirmed and signed.

The Chairman announced that the following members had been nominated to fill the vacancies which would occur on the Committee on the 30th September, 1940:—

Chairman: C. W. Marshall, B.Sc.

Vice-Chairman: W. Phillips.

Ordinary Members of Committee: D. C. Gall, A. G. O'Neill and W. G. Radley, Ph.D.(Eng.).

In the event of a ballot for the new Committee being required, Messrs. F. O. Barralet and L. J. Matthews were appointed scrutineers.

A lecture was then delivered by Mr. H. Warren, entitled "Insulation."

A vote of thanks to the lecturer, proposed by Mr. A. E. Jepson and seconded by Mr. F. J. Lane, was carried with acclamation.

PROCEEDINGS OF THE TRANSMISSION SECTION

38th Meeting of the Transmission Section, 10th April, 1940

Mr. F. W. Purse, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 13th March, 1940, were taken as read and were confirmed and signed.

The Chairman announced that the following members had been nominated to fill the vacancies which would occur on the Committee on the 30th September, 1940:—

Chairman: H. J. Allcock, M.Sc.

Vice-Chairman: S. W. Melsom.

Ordinary Members of Committee: W. Fennell, J. W. Leach, J. A. Lee, W. H. L. Lythgoe and E. T. Norris.

The following papers were then read and discussed:—

"The Development of a Pre-Stressed ('Toughened') Glass Insulator," by Mr. P. M. Hogg, B.Sc., Member.

"The Performance of Glass Insulators and Comparisons with Porcelain" (E.R.A. Report), presented by Mr. C. E. R. Bruce, M.A., B.Sc., and Dr. S. Whitehead, M.A., Associate Member.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

39th Meeting of the Transmission Section, 8th May, 1940

Mr. F. W. Purse, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 10th April, 1940, were taken as read and were approved and signed.

In the event of a ballot for the new Committee being required, Messrs. L. M. Jockel and J. W. Perkins were appointed scrutineers.

A paper by Mr. M. C. Hunter entitled "Mechanical Integrity in the Design of Electrical Circuit-Breakers," was read and discussed.

A vote of thanks to the author, moved by the Chairman, was carried with acclamation.

PROCEEDINGS OF THE WIRELESS SECTION

155th Meeting of the Wireless Section, 3rd April, 1940

Dr. E. B. Moullin, M.A., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 6th March, 1940, were taken as read and were confirmed and signed.

The following papers were read and discussed:—

"Reflection Curves and Propagation Characteristics of Radio Waves along the Earth's Surface," by Dr. J. S. McPetrie, Associate Member, and Miss A. C. Stickland, M.Sc.

"An Experimental Investigation of the Propagation of Radiation having Wavelengths of 2 and 3 Metres," by Dr. J. S. McPetrie, Associate Member, and Mr. J. A. Saxton, B.Sc

"Radio Direction-Finding on Wavelengths between 2 and 3 Metres (100 to 150 Mc./sec.)," by Dr. R. L. Smith-Rose, Member, and Dr. H. G. Hopkins, B.Sc.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

18th Informal Meeting of the Wireless Section, 23rd April, 1940

Dr. R. L. Smith-Rose took the chair at 6 p.m.

The minutes of the Informal Meeting held on the 27th February, 1940, were taken as read and were confirmed and signed.

A discussion on "War-Time Standardization" was

opened by Mr. P. R. Coursey, B.Sc.(Eng.), and his remarks were supplemented by Group Captain D. H. de Burgh, A.F.C., R.A.F.

At the conclusion of the discussion a vote of thanks was accorded to Mr. Coursey for his introductory remarks.

156TH MEETING OF THE WIRELESS SECTION, 1ST MAY, 1940

Dr. E. B. Moullin, M.A., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 3rd April, 1940, were taken as read and were confirmed and signed.

The Chairman announced that the following members had been nominated to fill the vacancies which would occur on the Committee on the 30th September, 1940:—

Chairman: W. J. Picken.

Vice-Chairman: T. E. Goldup.

Ordinary Members of Committee: L. W. Hayes, T. H. Kinman, R. P. Ross, B.Sc.(Eng.), and R. L. Smith-Rose, D.Sc., Ph.D.

In the event of a ballot for the new Committee being required, Messrs. S. R. Chapman, M.Sc., and F. Jervis Smith were appointed scrutineers.

A paper by Mr. A. D. Hodgson, Member, entitled "Civil Air Transport Communication," was read and discussed.

A vote of thanks to the author, moved by the Chairman, was carried with acclamation.

INFORMAL MEETINGS

228TH INFORMAL MEETING (29TH JANUARY, 1940)

Chairman: The President, Mr. Johnstone Wright.

Subject of Discussion: "Load-building in War-Time" (introduced by Mr. F. W. Purse).

Speakers: Messrs. J. I. Bernard, B.Sc.Tech., F. E. Rowland, P. P. Wheelwright, J. F. Shipley, A. G. Kemsley, F. Jervis Smith, F. L. Veale, Miss D. Vaughan, Messrs. J. L. Wilson, G. O. McLean, M.Eng., W. A. Ritchie, L. J. Luffingham and Miss C. Haslett, C.B.E.

229TH INFORMAL MEETING (12TH FEBRUARY, 1940)

Chairman: Mr. M. Whitgift.

Subject of Discussion: "Emergency Jointing of Cables" (introduced by Dr. P. Dunsheath, O.B.E., M.A.).

Speakers: Messrs. P. K. Davis, G. F. Kennedy, M.A., C. Kibblewhite, J. L. Wilson, J. F. Shipley, G. Davidson, W. F. Sands, R. E. G. Horley, P. P. Wheelwright, G. H. Fowler, E. A. Deacon, A. Morgan, S. H. Hart, H. G. Taylor, M.Sc., R. C. H. Connolly, J. K. Bell, T. Jackson, P. L. Spencer, B.Sc.(Eng.), J. Urmston and G. O. McLean, M.Eng.

230TH INFORMAL MEETING (26TH FEBRUARY, 1940)

Chairman: Mr. F. Jervis Smith.

Subject of Discussion: "The I.E.E. Wiring Regulations, 11th Edition" (introduced by Mr. H. J. Cash).

Speakers: Messrs. F. W. Purse, F. C. Raphael, F. J. Hawkins, Forbes Jackson, E. A. Pinto, D. Gough, F. L. Veale, E. Brown, H. G. Taylor, M.Eng., G. Davidson, E. Jacobi, W. H. Lythgoe, H. Hobbins, W. E. Chuter, W. E. Steward, R. Plummer, A. F. Steel and W. H. Brooks.

231ST INFORMAL MEETING (11TH MARCH, 1940)

(Joint meeting with The Institution of Civil Engineers, The Institution of Mechanical Engineers and The Institute of Welding.)

Chairman: Mr. J. R. Beard, M.Sc.

Subject of Discussion: "Emergency Repairs of Plant, with special reference to Welding" (introduced by Dr. S. F. Dorey.

Speakers: Messrs. E. S. Needham, C. H. Davy, Major J. Caldwell, J.P., Messrs. E. Kilburn Scott, W. A. Stanier, H. B. Fergusson, A. Ramsay Moon and G. B. Plows.

232ND INFORMAL MEETING (1ST APRIL, 1940)

Chairman: Mr. F. Jervis Smith.

Subject of Discussion: "Electro-Acoustics in Practice" (introduced by Mr. P. G. A. H. Voigt, B.Sc.(Eng.).

Speakers: Messrs. E. M. Frost, L. E. C. Hughes, Ph.D., B.Sc., W. Carr, J. Moir, G. A. C. Brown, J. L. Greatorex, J. E. Rhys-Jones, J. Cohen, A. Melchoir, F. Jackson, E. W. B. Jones and G. H. Munro.

233RD INFORMAL MEETING (15TH APRIL, 1940)

Chairman: Mr. A. G. Kemsley.

Subject of Discussion: "Adequate Domestic Equipment" (introduced by Mr. M. Whitgift).

Speakers: Mr. C. T. Melling, M.Sc.Tech., Mrs. P. MacKay, Messrs. E. Brown, H. R. Waters, F. E. Rowland, H. G. F. Lambe, Miss W. Hackett, Miss H. Minoprio, Messrs. G. Davidson, P. P. Wheelwright, H. G. Taylor, M.Sc., G. O. McLean, M.Eng., A. Cunnington, Mrs. M. Whitgift, Messrs. K. J. R. Cocke, B.Sc.(Eng.), F. Jervis Smith, E. A. Pinto, W. C. Dawson, F. B. P. Pearce, H. Brierley, and A. G. Kemsley.

ELECTIONS AND TRANSFERS

At the Annual General Meeting, held on the 9th May, 1940, the following elections and transfers were effected:—

Elections

Associate Members

Baxter, Charles Henry.
Benn, Sylvester Munro.
Bennett, Maurice Chesterton, Major, R. Signals.
Bhandari, R. C., B.Sc. Tech.
Boccacci, Victor Cesare T. A.
Chilcot, Arthur Leslie, B.Sc.
Cocking, Walter Tusting.
Falloon, Shirley Waldron H. W., B.A.
Glazier, Edward Victor D., B.Sc.
Gracie, James Johnstone.
Katzelis, Nicolas George.
Leath, Cleo. Sydney.
Lemmey, Claude Wilfred.
Lewis, Edward.
Lister, Thomas Vaughan, Wing Comdr. R.A.F.
McGinnety, Frank Edward, M.Sc.
Moscardi, Harry Lucius, Major, R.E.
Neale, James, B.Sc.(Eng.).
Passmoor, John.
Pither, Alfred George.
Pollitt, Arthur.
Root, Ernest Victor.
Ross, William, M.A.
Summers, Henry Edward, B.Sc.
Toas, Frank Bernard.
Watson, Percy Sylvester.
Young, James Roumieu, Capt. R.E.

Associates

Bell, Henry Arthur.
Dando, Alfred Price.
Hainsworth, Harold Percival.
Humphrey, Christopher Bernard.
Hunter, John Garner.
Lambert, Pierre Louis V.
McKeogh, Frederick Thomas.
Malovitzky, Gregory Zvi.
Metcalf, James Norman.
Mills, Thomas Herbert L.
Shaw, Frank Townley.
Swann, Harold Morris.
Wilkinson, Robert Ernest.
Woods, Arthur Sylvester.
Worth, William Donovan.

Graduates

Bird, Wilfred George.
Bonch, Vadim, B.Sc.(Eng.).
Chadwick, Reginald.
Crabtree, John Ashworth, B.A.
Desai, Chhotubhai Ranchhodji, B.E.
Eckford, Alexander Thomas.
Gledhill, Joe, B.Sc.
Harris, Leslie Frank.
Hollingworth, James Wallace, B.Sc.
Innes-Crump, John Edwin, B.A.
Jenkins, Stanford de Trevellyn, B.Sc.
Keogh, Hubert Hedigan S.
Kohli, Shanti Sroup, M.Sc.
Larkin, Alfred Spencer.
Mellersh, Frederick Chase.
Murti, Codati Narayana.
Pyke, Stephen.
Randall, Henry, B.Sc.
Self, Percy Noel.
Smith, Harold Arthur, B.Sc.(Eng.).
Soutter, Sydney Alexander, B.Sc.(Eng.).
Steel, John Exton, M.A. (Eng.), Lieut.
Toule, John Henry, B.Sc.
Whitwam, Thomas Cotton.

Students

Ackland-Snow, Philip Edric.
Ahmad, Mushtaq, B.Sc.
Ahmad, Nizamuddin.
Ahmed, Syed Rashid.
Akehurst, George Bertram.
Akerhielm, Claes Edward.
Akhtar, Mohamed.
Alim, Abdul.
Alkin, Gerald Thompson.
Appleton, Sidney Walter.
Apte, Bhagwan Madhav.
Asadullah, S.
Athavale, Bhaskar Narayan, B.Sc.
Aziz, Malik Mohd.
Baker, Guy Spencer.
Banerjee, Ajoy Kumar, B.Sc.
Banerjee, Nripendra Nath, M.Sc.
Bar-Giora, Meir.
Barrow, Myer.
Battiwala, Behli Phirozeshah, B.Sc.
Bhagat, Milkhi Lal.
Bhagvati, Ratnavaden Manilal.
Bhall-e-Sultani, Virendra Bahadur S.
Bhatia, Satish Chandra R.
Bird, Thomas Richard.
Bishop, Geoffrey Ernest.
Blandford, Frank Albert.
Braithwaite, Frederick Hughes.
Burgess, Roy Harrod.
Calvert, Percy, jnr.
Campbell, Douglas.
Carter, Frederick Thompson.
Chandratrey, Keshav Ganesh.
Charlesworth, George Ernest.
Chaudhri, D. P.
Chube, Rajaram Ganpat.
Chupiramaniam, Thampipillai.
Cole, Patrick.
Comyn, Victor Lewis J.
Crouch, George Walter.
Crouch, Horace Henry.
Curzon, Roger Walker.
Daniel, Paul Davis.
Davies, Herbert Alan.
De, Mihir Lal, B.Sc.
Dickie, John.
Dillon, Patrick Joseph.
Doctor, Pestonji Bomonji.
Doshi, Kantilal Narandas, B.E.

Students—continued

Downes, John Godkin.
Driver, Jal Shavekshaw.
Du Preez, Charles Marthinus J.
Dyer, John Henry.
Elavia, Framjee Dinshawjee.
Eravelle, Francis J.
Farrall, Terence.
Fernando, Illakuttige Aloysius.
Fernando, James Patrick A. D.
Fisicaro, Joseph Andrew.
Franks, John Fergusson.
Fulford, Thomas Henry.
Gaitonde, Ganapati Ghanasham.
Garga, Darshan Lall.
George, Donald.
Ghosh, Amal Kumar, M.Sc.
Godkar, Rajaram Vishnu.
Goil, Kaluram Rameshwardas.
Gole, Shripad Shanker, B.Sc.
Goodyer, Philip Alfred.
Gopinath, E.
Goswami, Amar Krishna.
Gould, Godfrey.
Grant, Michael.
Grover, Lekh Raj.
Halliday, Jack Hubert.
Harrison, John Michael.
Henderson, John Henry.
Henderson, Thomas Edward.
Hill, Richard Edgar.
Hing, Awing.
Homan, Percy George.
Honess, Leslie George.
Horton, Arthur.
Hunter, John.
Husk, Clifford Stanley.
Ingham, William Ellis.
Iyer, S. Mahadeva, B.A.
Jackson, Peter Bertram B.
Jagad, Bakulchandra H.
Jain, Sudarshan Lal.
Jephcott, David Bramwell.
Jnaneswaran, K.
Jones, Frank Richard R.
Kam, Satya.
Kanagarajah, Manickam.
Kapil, Balbhadar Sain, B.Sc.(Eng.).
Karve, A. V.
Kaye, Ernest Joseph.
Kazi, Imtiyazali Mumtazali.
Kemp, Kenneth William L.
Kennett, Peter.
Keskar, Vasant Vishwanath.
Khambhati, Nautamlal Natvarlal.
Khan, Manzoor Mahdi.
Khan, Mohammad Yamin.
Khardekar, Madhava Narayan R.
Khatri, Thakar Das.
Khera, Narain Dass.
Khosla, Harbhajan Lal, M.Sc.
Khullar, Narain Datta.
Kirpalani, Naraindas Detaram.
Knights, Herbert Russell.
Kukde, Pralhad Vasantrao.
Lal, Ram Chandar.
Lama, Ved Prakash.
Langton, Harold James.
Lawrence, James Scott.
Leach, Alfred Allen J.
Leech, Ronald Francis.
Lilley, Martin.
Lister, Cyril.
McIntyre, Harry Atkinson.
McKay, James.
Mackay, James Weir.
McMaster, Harold Sinclair.
McMillan, Roderick Duncan.
Madan, Bishambernath Motandass.
Magee, Thomas Robert.
Majumdar, Debidas, B.Sc.
Malhotra, Harbans Lal.
Malik, Siri Krishana.
Marfatia, Manek Kaikhusroo.
Massil, Lewis.
Menon, Pooyath Raman K.
Mistry, Dhanjishaw Jehangirji.
Mitchell, Geoffrey Duncan S.
Mitchell, Victor John.
Mohan, Matta Madan, B.Sc.
Mooneshinghe, Sumeda Gamini.
Morton, George Basil S.
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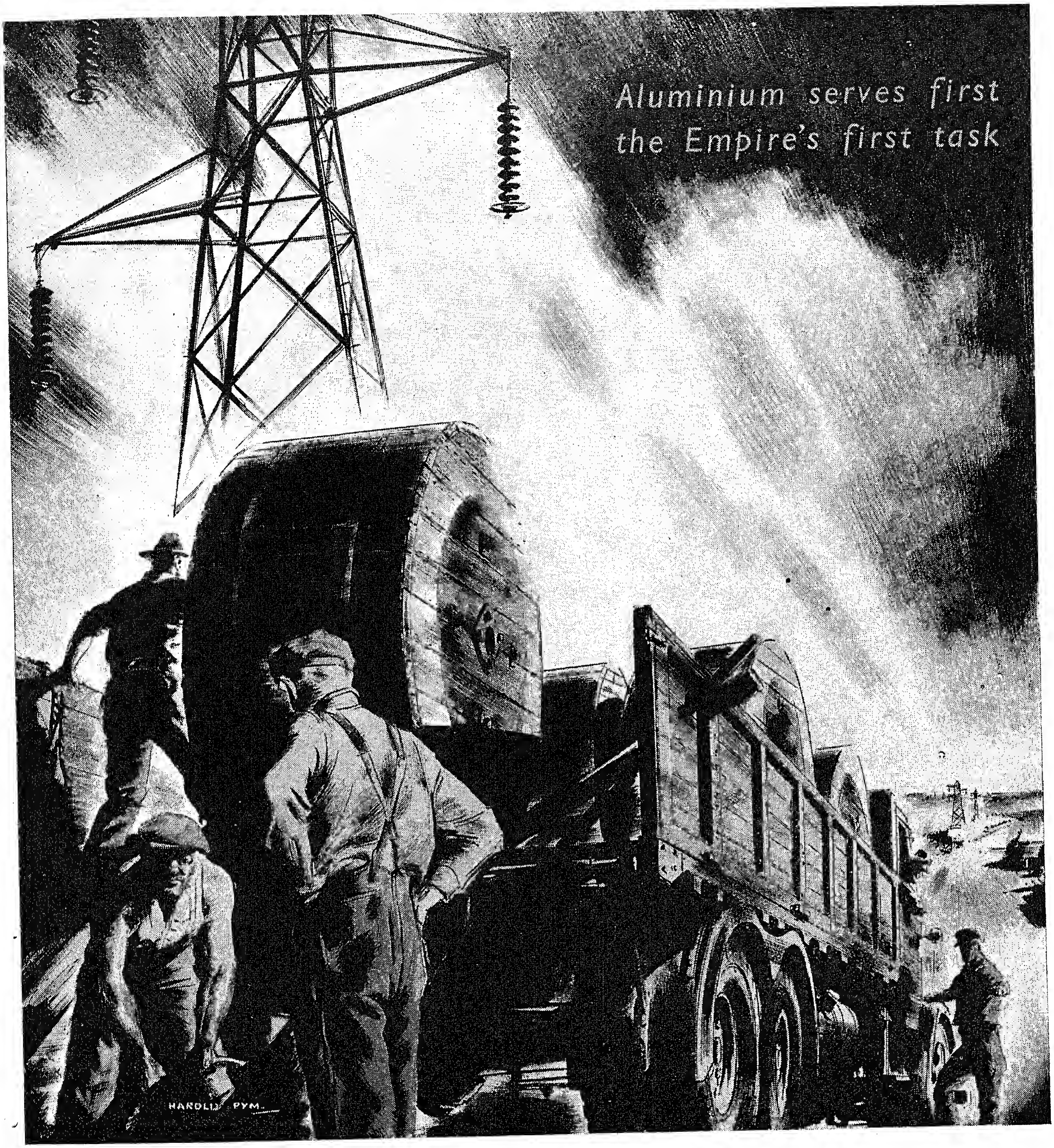
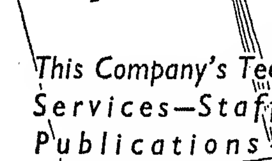


Erection of steel-cored aluminium conductors



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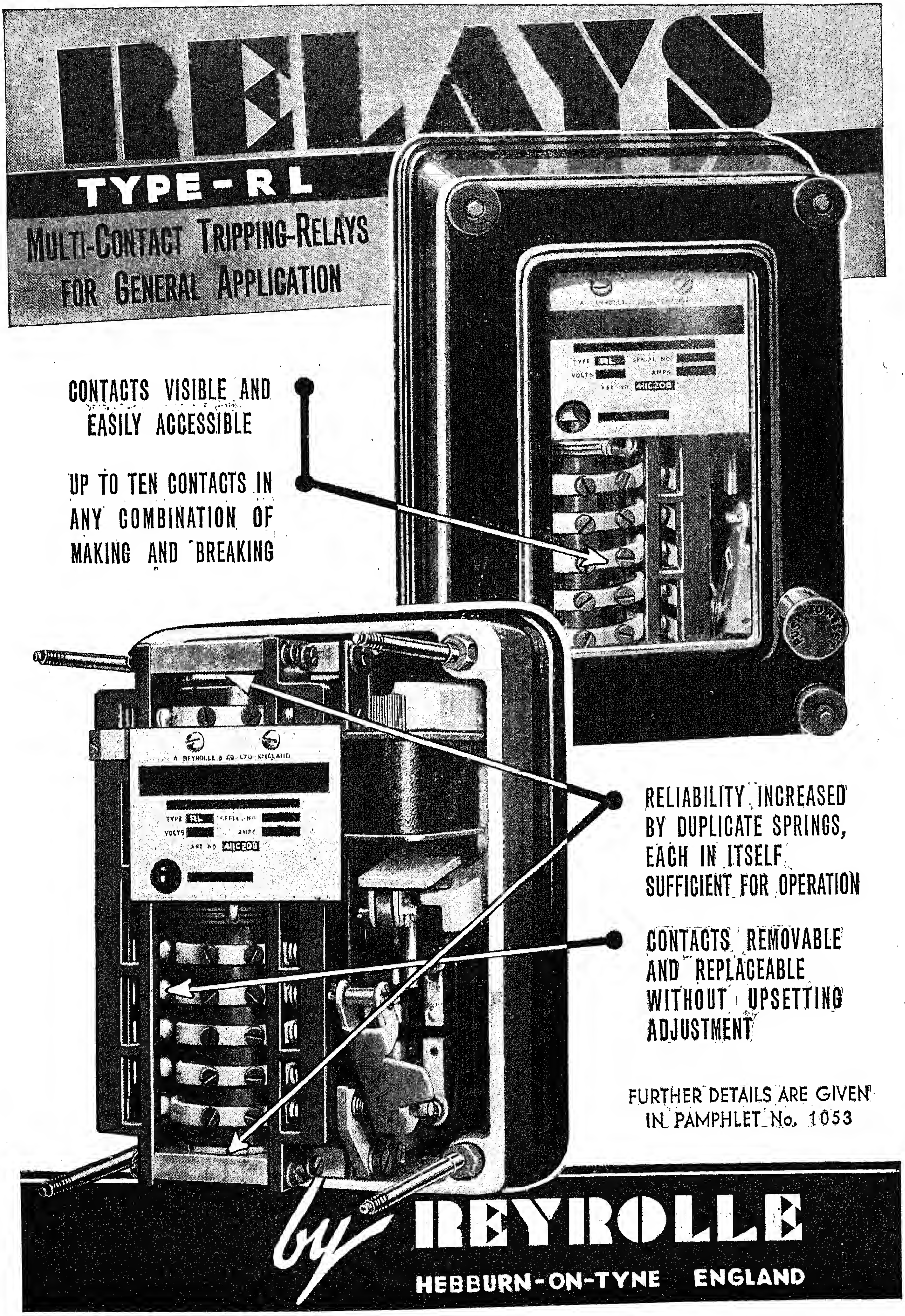
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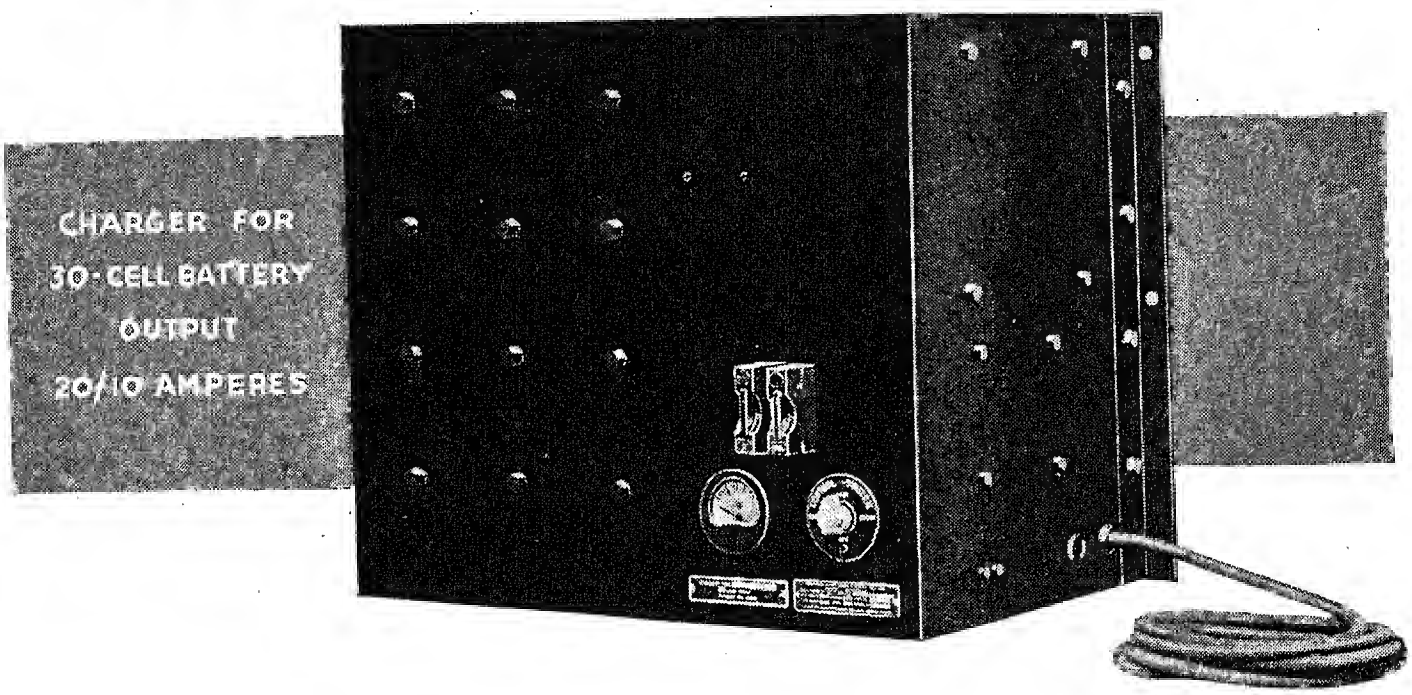

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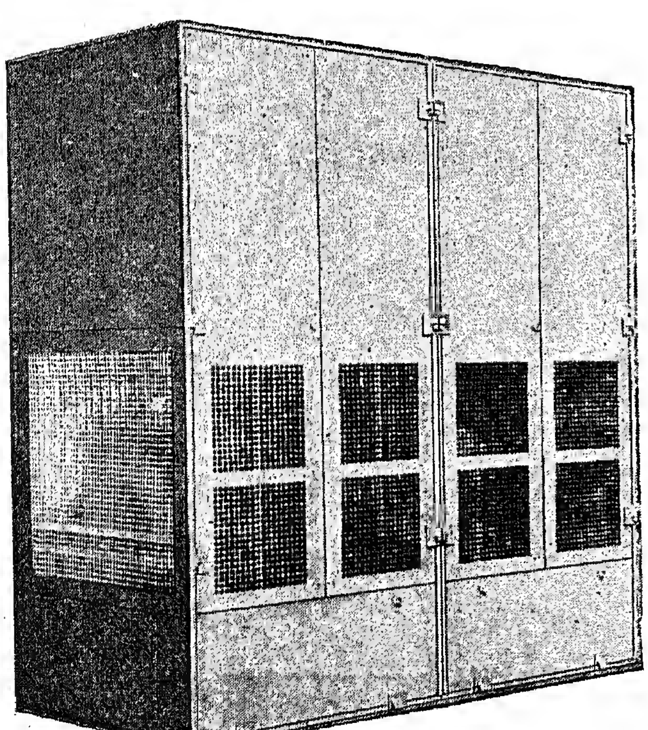
Independent Opinion

[The "Electrical Times" of February 22, 1940 commenting on the I.E.E. Review of Progress]—

> ...information for bringing the busy engineer up to date. Some people believe that direct current is gradually fading out of existence; Mr. Juhlin comments on the conspicuous increase in the demand for d.c. motors in the last few years; it is occurring throughout most of the industries using an electric drive. This is probably due to the complex nature of modern industrial processes, which call for variable speeds over a wide range, great ease of control, and economic advantages resulting therefrom. Another d.c. item is the fact that generators having a normal output of 1,800 kilowatts are now being built, generally for rolling mills or pit-winding gear. It is strange that there are so many types of a.c. motors which, with special control arrangements, permit one to obtain almost any variation in speed desired; yet the d.c. motor is still first favourite with thousands of engineers who know what they want.
>
> **METEOR**



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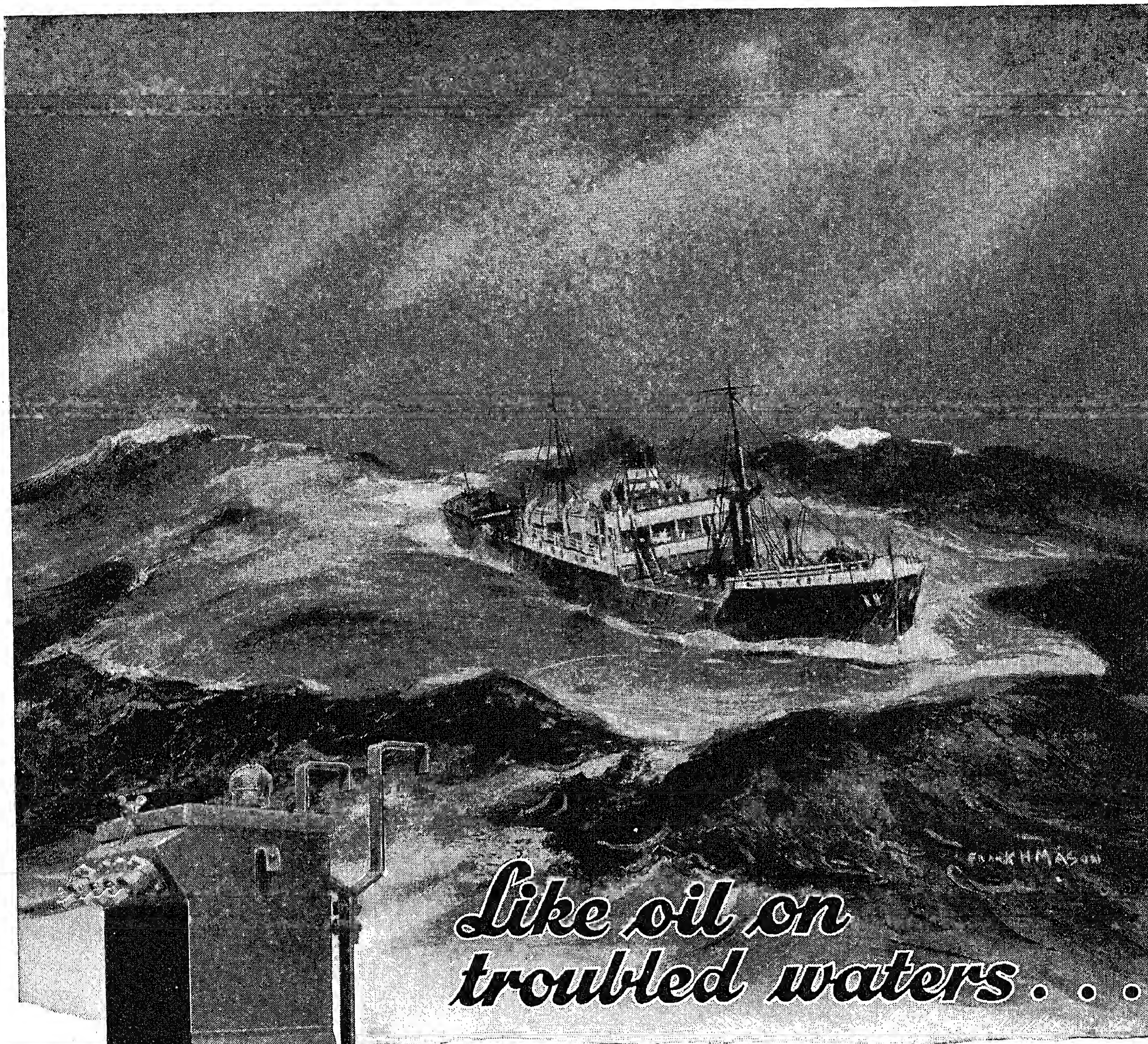

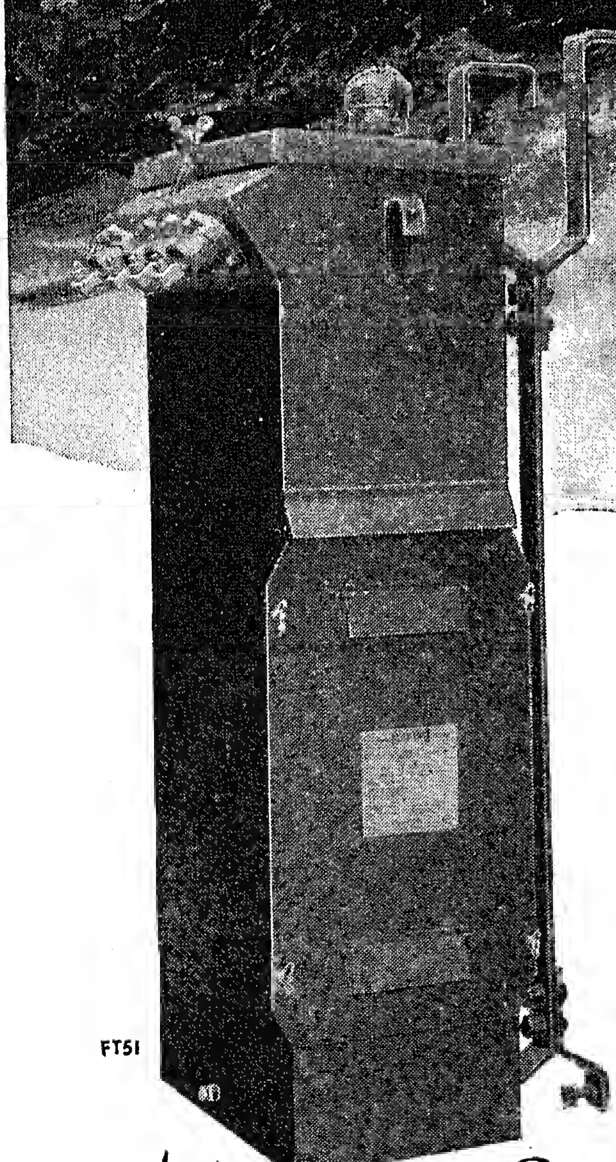

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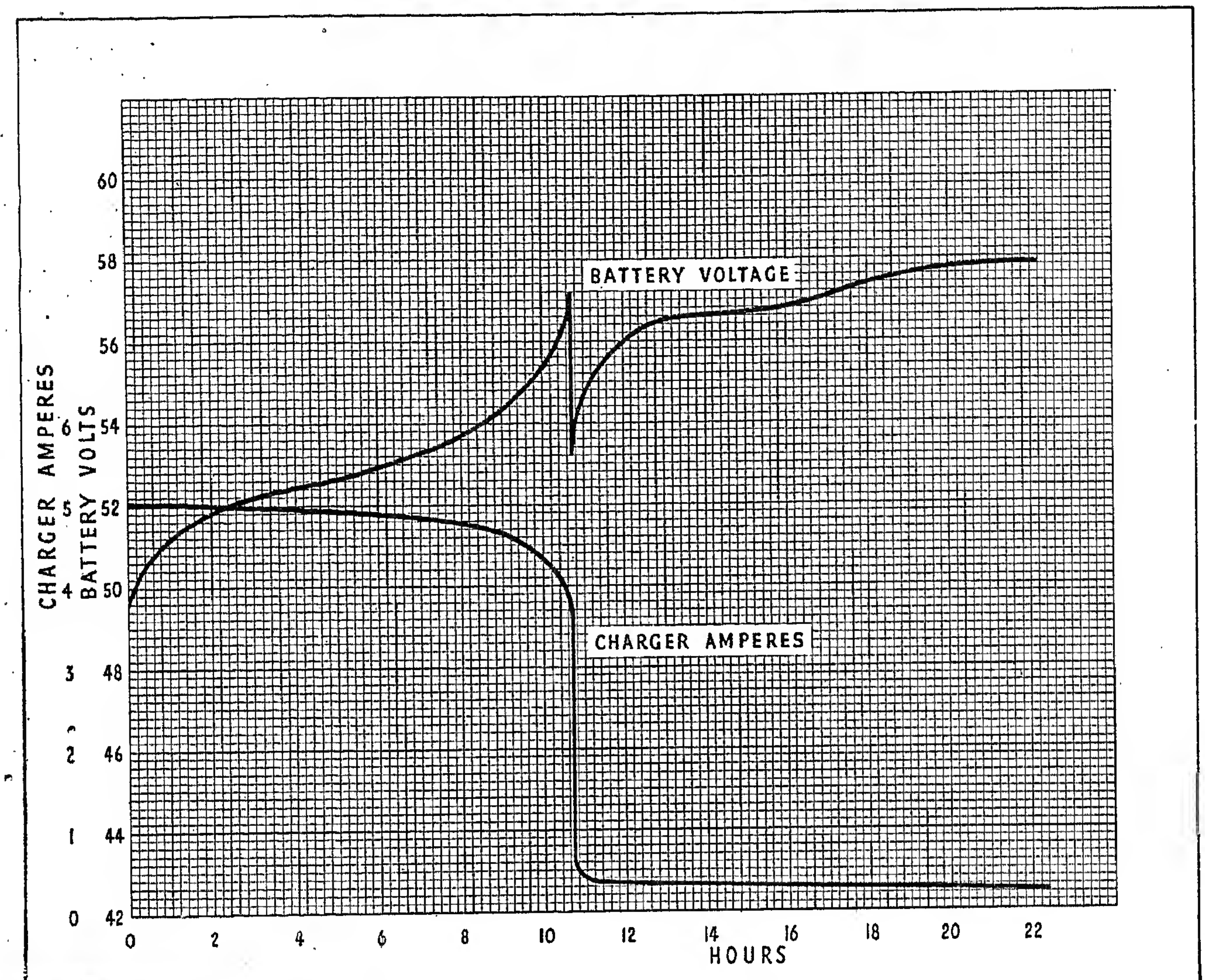

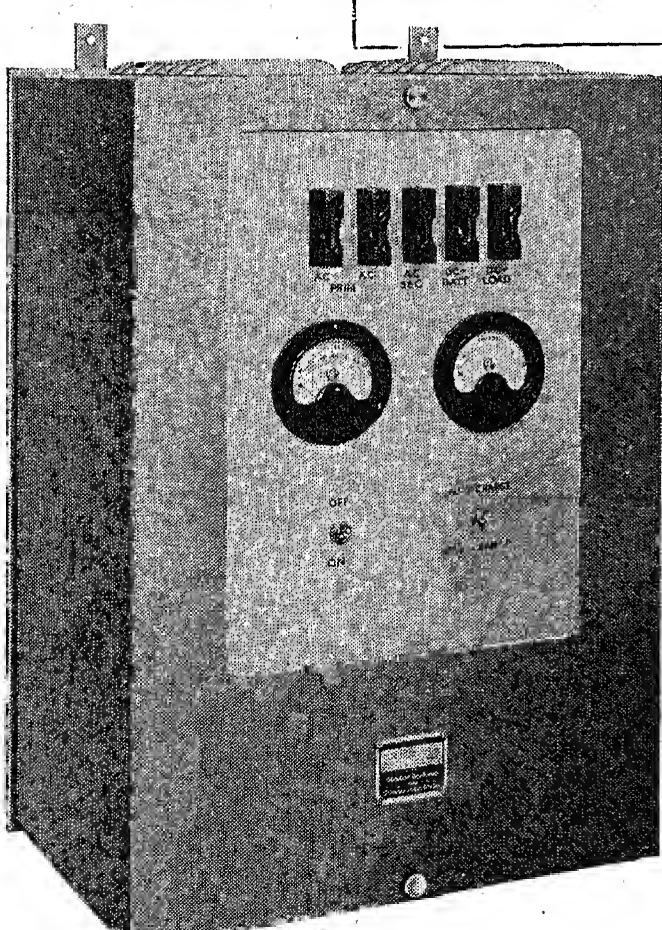

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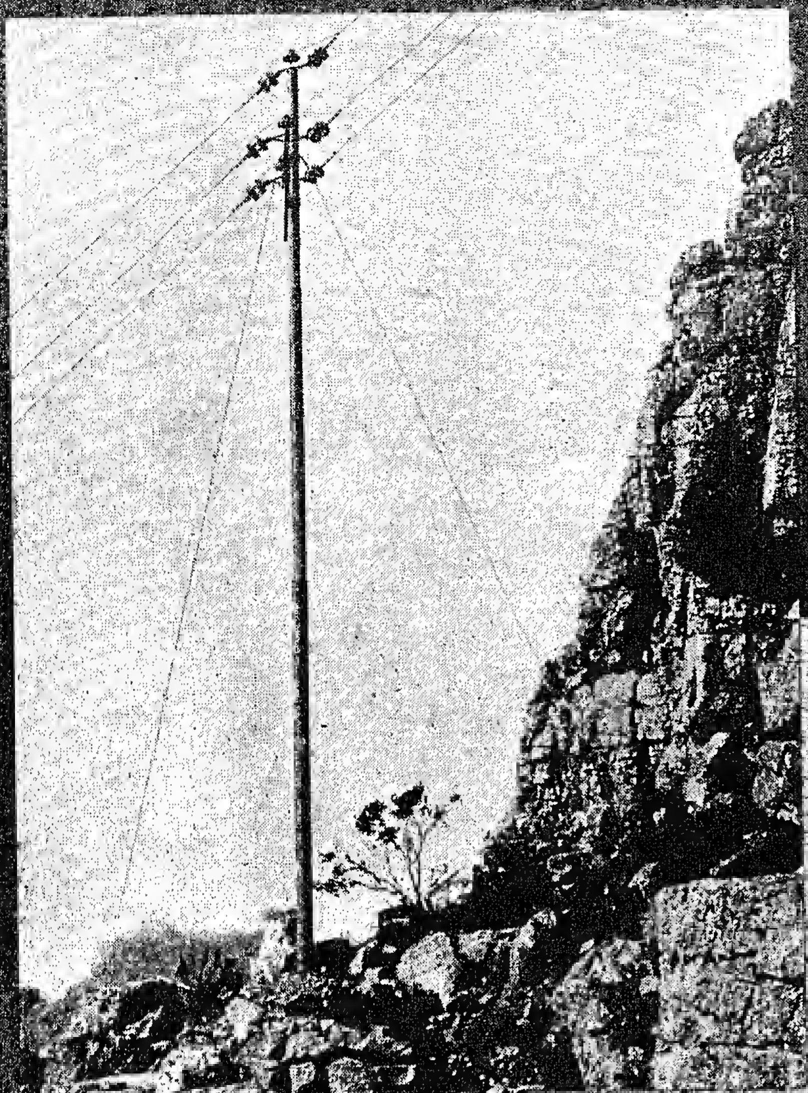

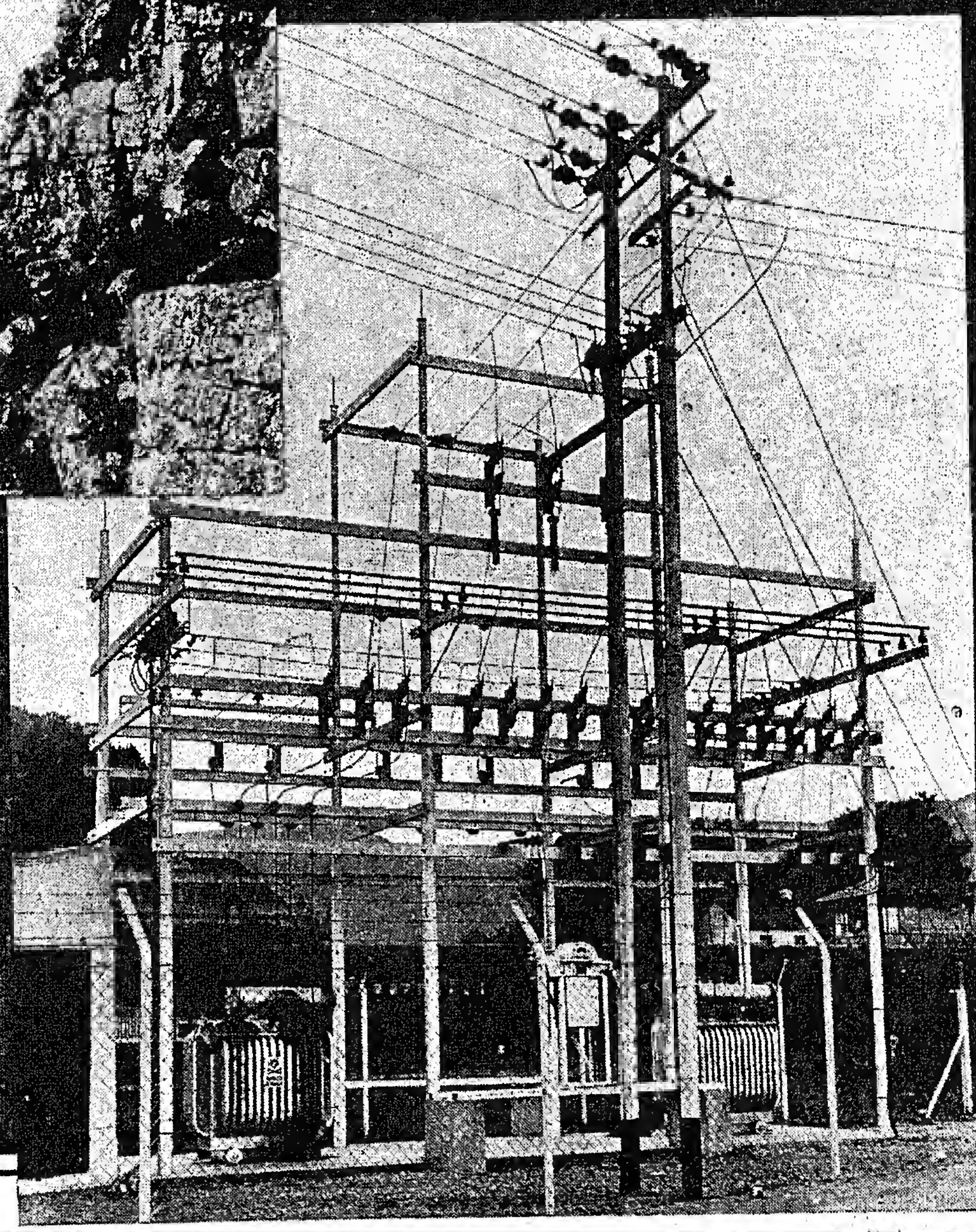

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